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ROTARY WING FLIGHT



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FIELD MANUAL

NO. 1-51

*FM 1-51

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, 16 April 1979

INTRODUCTION

ROTARY WING FLIGHT

History reveals that discoveries made by world explorers have resulted from their perseverance in overcoming fear of the unknown. Christopher Columbus is an example of such an explorer. Fear of what would be encountered on his journey to America dominated his subconscious; however, his vision of discovery and how it would affect the world compelled him to explore the unknown. This analogy describes the present thinking of many of our Army aviators relating to night terrain flight. A new horizon confronts Army aviators and it must be explored. In past conflicts, the ground commander used night airmobility sparingly; however, future wars will require extensive employment of night air assault forces. To perform around-the-clock aviation support, the Army aviator must be prepared to conduct night air assault operations. Because the enemy has more sophisticated air defense weapons, the helicopter is forced to fly lower to the ground. This technique allows the aviator to take advantage of vegetation and terrain obstacles to mask the helicopter from the enemy's radar. Through training and improved night vision devices, the aviator can develop confidence in his ability to conduct night terrain flight and overcome the fear of the darkness. His imaginative and innovative solutions to problems created by darkness will contribute to the success of night terrain flight. To stereotype tactical employment of Army aviation assets is to court defeat; but to develop effective countermeasures against the air defense threat is to remove a principal obstacle to the commander's victory.

STATEMENT

THE WORD "HE" IS INTENDED TO INCLUDE BOTH THE MASCULINE AND THE FEMININE GENDERS. ANY EXCEPTIONS TO THIS WILL BE SO NOTED.

*This Field Manual supersedes FM 1-1, 1 October 1975; FM 1-51, 30 May 1974; and TC 1-28, 15 February 1976, including all changes.

USER COMMENTS

Readers are encouraged to submit recommended changes and comments to improve the publication. Reasons, as well as substitute statements or paragraphs, should be provided for each recommended change. Comments should be keyed to specific page, paragraph, and line of the manual. Comments/recommended changes should be submitted on DA Form 2028 (Recommended Changes to Publications and Blank Forms) directly to Commander, United States Army Aviation Center and Fort Rucker, ATTN: ATZQ-TD-TL, Fort Rucker, Alabama 36362.

PREFACE

PURPOSE AND SCOPE

This manual is written to provide a reference for the:

☐ Initial entry rotary-wing aviator student during the primary and advanced stages of training.

☐ Academic instructor as a reference textbook for presenting instruction.

☐ Instructor pilot as a guide for reinforcement of the student's fundamental knowledge of rotary-wing flight.

☐ Check pilot as a guide for flight evaluation of the student's fundamental knowledge of rotary-wing flight.

☐ Rated aviator as a guide when undergoing instructor pilot training and aircraft qualification training, and for maintenance of fundamental knowledge of rotary-wing flight.

☐ Unit commander as a guide for unit training in terrain flying, night flight, and specialized activities such as rescue hoist operations, external load operations, and formation flight.

☐ This field manual has been written in consonance with international standardization agreements as identified in appendix A.

GENERAL

The content of this publication has been arranged to present the elements of applied aerodynamics which relate directly to the problems of flying operations and to provide as complete as possible a reference for terrain and night flying. Hence, the text material is applicable to the problems of flight training, transition training, and general flying operations. The manner of presentation throughout the text has been designed to convey the elements of theory, practical experience, and application. As a result, the text material could be applicable to supplement class instruction and provide reading material as a background for training and flying operations.

Specialized mathematical detail for aerodynamics and night flight has been omitted for the sake of simplicity and clarity of presentation wherever it was considered unnecessary in the field of flying operations. Basic fundamental principles of night flight are provided which the aviator must understand in order to effectively develop and increase night flying skills.

AIRCRAFT DATA

Information on helicopter configuration and performance under specific conditions is found in the appropriate aircraft Operator's Manual.

FM 1-51

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CHAPTER 1

PROPERTIES OF THE ATMOSPHERE

COMPOSITION

Helicopter performance is largely dependent on the properties of the airmass or atmosphere which surrounds the earth. The atmosphere is composed of about 78 percent nitrogen, 21 percent oxygen, and 1 percent argon, carbon dioxide, and other dry gases. Water vapor may vary from near zero to 3 to 5 percent by volume. At the normal speeds at which helicopters operate, the chemical composition is not important, and air can be considered to be a homogeneous mixture of its constituent gases.

STATIC PRESSURE

The absolute static pressure of the air is a property of primary importance. The static pressure of the air at any altitude results from the mass of air supported above that level. At standard sea level conditions, the static pressure of the air is 2,116 pounds per square foot (psf), 14.7 pounds per square inch (psi), 29.92 inches of mercury (Hg), or 1013.2 millibars (mb). The pressure decreases as altitude increases, because less air remains above. At 40,000 feet altitude, the static pressure is only about 19 percent of the sea level value.

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The static pressure at the earth's surface varies from place to place around the earth at any given time. Any given location on the earth's surface experiences changes in static pressure from day to day. For convenience, standard sea level static pressure (P_0) is defined as:

$$\begin{aligned}
 P_0 &= 2116 \text{ psf} \\
 &= 14.7 \text{ psi} \\
 &= 29.92 \text{ in. Hg} \\
 &= 1013.2 \text{ mb}
 \end{aligned}$$

A static pressure ratio, denoted δ (delta), is used in aerodynamic and performance calculations. The static pressure ratio is the proportion of the ambient static pressure and the standard sea level static pressure. In a standard atmosphere, the

Static Pressure Ratio

$$= \frac{\text{Ambient static pressure}}{\text{Standard sea level static pressure}}$$

$$\delta = p/p_0$$

pressure ratio δ (delta) has a value of 1.0 at sea level and values less than 1.0 at higher altitudes. Thus, a pressure ratio of 0.5 means that existing static pressure is one-half the standard sea-level value.

TEMPERATURE

The absolute temperature of the air is another property that is important to helicopter performance. Temperature is normally measured using the Fahrenheit or Celsius (formerly called centigrade) scales. These scales are based on the boiling and freezing points of water. Zero degrees Celsius corresponds to 32° Fahrenheit for the freezing point, and 100° Celsius corresponds to 212° Fahrenheit for the boiling point. At -40° both scales happen to have the same value. To convert one scale to the other, use the formulas below:

$$^{\circ}\text{C} = 5/9(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5^{\circ}\text{C} + 32$$

Two more fundamental temperature scales are the Kelvin scale and the Rankine scale. Zero on both of these scales is absolute zero, the point at which no molecular kinetic energy is observable. Absolute zero is equal to -273°C or -460°F. Fahrenheit and Celsius can be converted to Rankine and Kelvin as follows:

$$^{\circ}\text{R} = ^{\circ}\text{F} + 460$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

Kelvin and Rankine absolute scales more accurately reflect the true behavior of the temperature properties of the atmosphere so are used in scientific computations. Meaningful temperature relationships are computed by comparing standard temperature to ambient temperature using a ratio of appropriate absolute values. Standard temperature has been established as 15°C or 59°F, which correspond to 288°K or 519°R. Temperature ratio is assigned the shorthand notation of θ (theta). Ambient temperature is denoted by T and standard temperature by T_0 .

Temperature Ratio

$$= \frac{\text{Ambient air temperature}}{\text{Standard sea level air temperature}}$$

$$\theta = \frac{T}{T_0}$$

If ambient temperature (T) is measured as 20°C, θ is computed as follows:

$$\theta = \frac{20^{\circ}\text{C} + 273}{15^{\circ}\text{C} + 273} = \frac{293^{\circ}\text{K}}{288^{\circ}\text{K}} = 1.017$$

In a standard atmosphere, θ (theta) has a value of 1.0 at sea level and values less than 1.0 at higher altitudes.

Sigma is the proportion of the ambient air density ρ and standard sea level air density (P_0).

DENSITY

The density of air is a property that directly affects helicopter performance. Density of air is simply the mass of air per unit volume and is denoted by ρ (rho). It is a direct measure of the quantity of matter in each cubic foot of air and is expressed in slugs per cubic foot (slug/ft³).

$$\text{Density (} \rho \text{)} = \frac{\text{Mass}}{\text{Unit volume}}$$

Air at standard sea level conditions weighs 0.0765 pounds per cubic foot and has a density of 0.002378 slugs per cubic foot. The weight and mass of a cubic foot of air decrease as altitude increases. At an altitude of 22,000 feet, the air density is about one-half of the sea-level value; and at 40,000 feet, only about 25 percent of the sea-level value. Since the density of the air working on an airfoil directly affects the amount of aerodynamic force produced, it becomes apparent that helicopter performance will be degraded in the lower density conditions normally found at higher altitudes.

A density ratio, denoted by σ (sigma), is often used in aerodynamic computations.

Density Ratio

$$= \frac{\text{Ambient air density}}{\text{Standard sea level air density}}$$

$$\sigma = \rho / \rho_0$$

In a standard atmosphere, σ (sigma) has a value of 1.0 at sea level and values less than 1.0 at higher altitudes.

A general gas law defines the relationship of pressure, temperature, and density when there is no change of state or heat transfer. Simply stated, "The gas law says that density varies directly with pressure and inversely with temperature." For example, if density is held constant, pressure and temperature are directly proportional. Or, if temperature is constant, increases in pressure cause increases in density, and vice versa. If the values of any of the two variables are known, the value of the third can be determined. Thus, if pressure and temperature are known, density can be calculated.

$$\text{Density Ratio} = \frac{\text{Static pressure ratio}}{\text{Temperature ratio}}$$

$$\sigma \text{ (sigma)} = \frac{\delta \text{ (delta)}}{\theta \text{ (theta)}}$$

Air density is also inversely proportional to humidity. Water vapor is lighter than dry air; consequently, moist air is lighter than dry air and is less dense. If humidity increases, the density of air will decrease, causing it to be less effective in producing an aerodynamic force from an airfoil.

STANDARD ATMOSPHERE

The International Civil Aviation Organization (ICAO) has defined a standard atmosphere to provide a common denominator for comparison of aircraft and a calibration standard for aircraft system

manufacturers. The ICAO standard atmosphere is partially shown in figure 1-1 and represents conditions averaged over the entire world during a year's time.

Since all aircraft performance is compared and evaluated in the environment of the standard atmosphere, all of the aircraft instrumentation is calibrated for the standard atmosphere. Because operating conditions are seldom equal to the standard atmosphere, certain corrections must apply to instrumentation as well as aircraft performance to properly account for non-standard atmospheric conditions.

Altitude (ft)	Density (slugs/ft ³)	Density Ratio	Pressure (psf)	Pressure Ratio	Temperature		Temperature Ratio	Speed of Sound (knots)
					°F	°C		
<i>h</i>	<i>ρ</i>	<i>σ</i>	<i>p</i>	<i>δ</i>			<i>θ</i>	<i>a</i>
0	0.002377	1.0000	2116	1.0000	59.00	15.00	1.0000	661.7
1,000	0.002308	0.9711	2041	0.9644	55.43	13.02	0.9931	659.5
2,000	0.002241	0.9428	1968	0.9298	51.87	11.04	0.9862	657.2
3,000	0.002175	0.9151	1897	0.8962	48.30	9.06	0.9794	654.9
4,000	0.002111	0.8881	1828	0.8637	44.74	7.08	0.9725	652.6
5,000	0.002048	0.8617	1761	0.8320	41.17	5.09	0.9656	650.3
6,000	0.001987	0.8359	1696	0.8014	37.60	3.11	0.9587	647.9
7,000	0.001927	0.8106	1633	0.7716	34.04	1.13	0.9519	645.6
8,000	0.001868	0.7860	1572	0.7428	30.47	-0.85	0.9450	643.3
9,000	0.001811	0.7620	1513	0.7148	26.90	-2.83	0.9381	640.9
10,000	0.001755	0.7385	1455	0.6877	23.34	-4.81	0.9312	638.6
11,000	0.001701	0.7156	1400	0.6616	19.77	-8.79	0.9244	636.2
12,000	0.001648	0.6933	1346	0.6361	16.21	-8.77	0.9175	633.8
13,000	0.001596	0.6714	1294	0.6115	12.64	-10.76	0.9106	631.4
14,000	0.001545	0.6500	1243	0.5874	9.07	-12.74	0.9037	629.0
15,000	0.001496	0.6292	1194	0.5643	5.51	-14.72	0.8969	626.7
20,000	0.001266	0.5328	972.5	0.4595	-12.32	-24.62	0.8625	614.6
25,000	0.001065	0.4481	785.3	0.3711	-30.15	-34.53	0.8281	602.2
30,000	0.000889	0.3741	628.4	0.2970	-47.98	-44.43	0.7937	589.5
35,000	0.000737	0.3099	498.0	0.2353	-65.82	-54.34	0.7594	576.6
36,089	0.000708	0.2971	472.7	0.2234	-69.70	-56.50	0.7519	573.8
40,000	0.000585	0.2462	391.7	0.1851	-69.70	-56.50	0.7519	573.8
50,000	0.000362	0.1522	242.2	0.1145	-69.70	-56.50	0.7519	573.8
60,000	0.000224	0.0941	149.8	0.0708	-69.70	-56.50	0.7519	573.8

FIGURE 1-1. ICAO STANDARD ATMOSPHERE.

Pressure altitude is one term used to correlate aerodynamic performance in the nonstandard atmosphere. It is the altitude in the standard atmosphere corresponding to a particular pressure. For example, a pressure of 1,572 pounds per square foot (or a pressure ratio of 0.7428) would be expressed as 8,000 feet pressure altitude (fig 1-1). It has nothing to do with the physical altitude of the aircraft above the ground or above sea level. It is only a more convenient way of expressing pressure and serves to provide a common frame of altitude reference for aircraft operating in the same areas of the atmosphere.

The aircraft altimeter is a pressure sensing instrument that is calibrated to indicate altitude in the standard atmosphere. By adjusting the instrument for nonstandard conditions, the pilot can maintain or change to a pressure altitude that will provide altitude separation from other aircraft that are using the same system and airspace.

DENSITY ALTITUDE

A more appropriate term for correlating aerodynamic performance in the non-standard atmosphere is density altitude. Density altitude is the altitude in the standard atmosphere corresponding to particular value of air density. Computation of density altitude involves consideration of pressure (pressure altitude) and temperature. Figure 1-2 illustrates how temperature and pressure altitude combine to produce a certain density altitude. For example, a pressure altitude of 3,000 feet and a temperature of +18°C result in an approximate density altitude of 4,000 feet.

Density altitude can be calculated using the density altitude formula shown below. (The formula is accurate for dry air.)

$$DA = PA + (FAT - STD \text{ Temp}) 120$$

Where DA = density altitude

PA = pressure altitude

FAT = free air temperature

STD Temp = standard temperature

120 = a constant in feet

If PA is 3,000 feet, FAT is +30°C, and STD Temp is 15°C, the calculation would be as follows:

$$DA = 3,000 + (30 - 15) 120$$

$$DA = 3,000 + (15) 120$$

$$DA = 3,000 + 1800$$

$$DA = 4,800 \text{ feet}$$

Density altitude has a strong effect on helicopter performance as reflected in the performance charts found in chapter 7 of Army aircraft operator's manuals. The performance charts tell the aviator what performance to expect from the helicopter under given conditions of pressure altitude, temperature, gross weight, airspeed and torque settings. An example of a hover (torque required) chart from the AH-1S operator's manual is at figure 1-3. This chart is typical of the type performance charts found in most Army operator's manuals and illustrates the effects of temperature and pressure on helicopter performance.

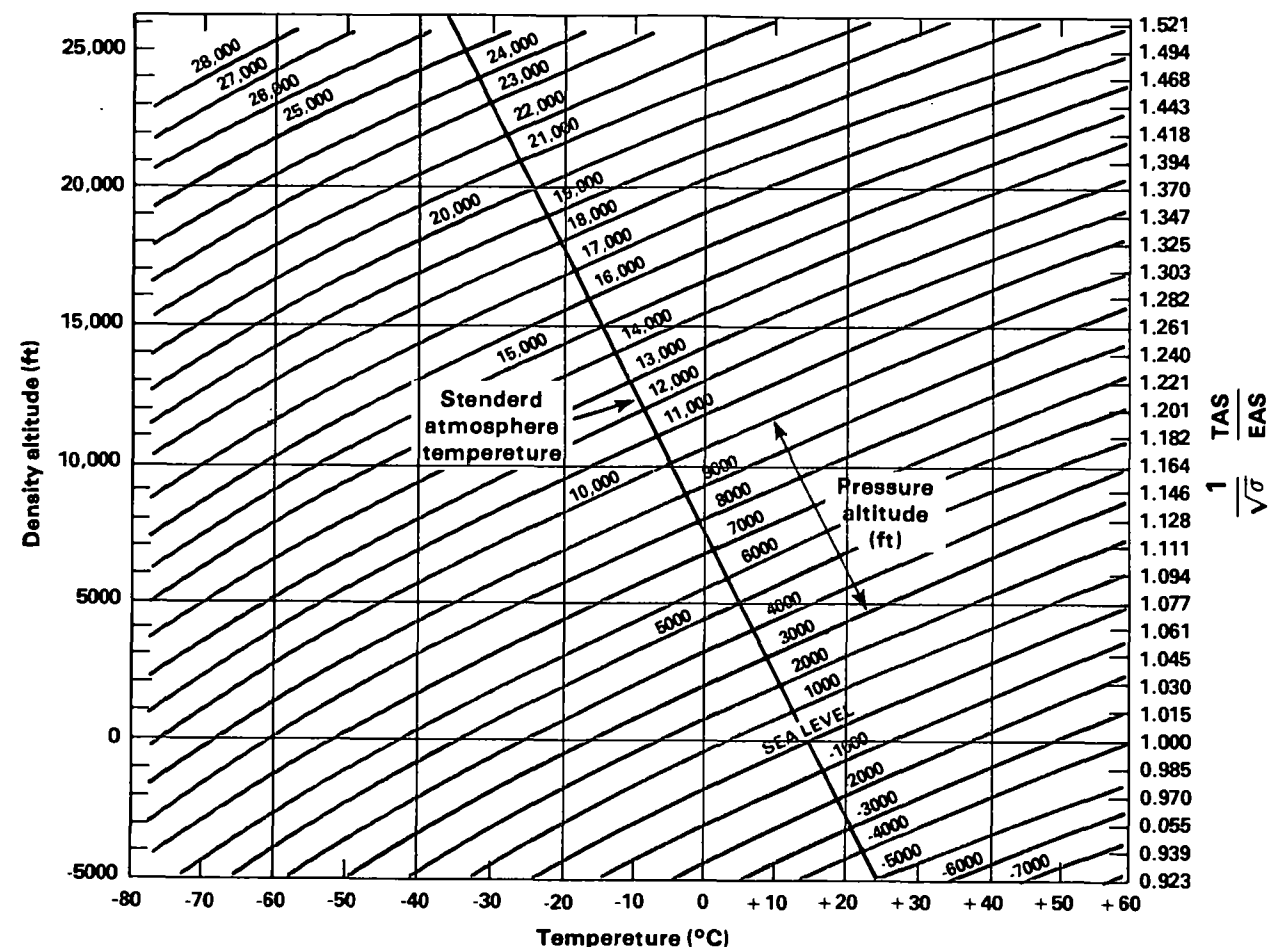


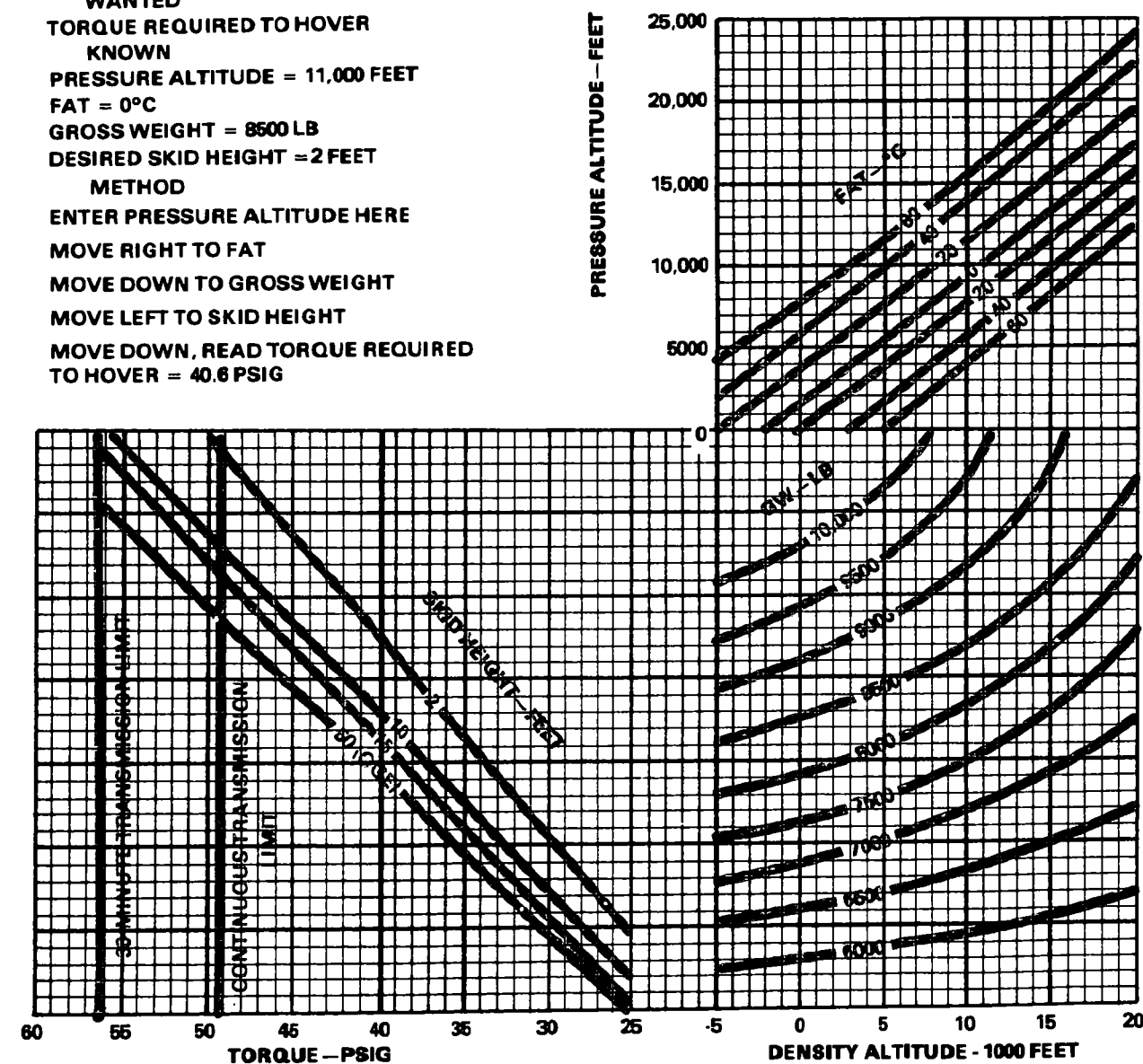
FIGURE 1-2. DENSITY ALTITUDE, PRESSURE ALTITUDE, AND TEMPERATURE.

HOVER
TORQUE REQUIRED
ALL CONFIGURATIONS 324 ROTOR/6600 ENGINE RPM
LEVEL SURFACE CALM WIND

HOVER
AH-1S
T53-L-703

EXAMPLE

WANTED
 TORQUE REQUIRED TO HOVER
KNOWN
 PRESSURE ALTITUDE = 11,000 FEET
 FAT = 0°C
 GROSS WEIGHT = 8500 LB
 DESIRED SKID HEIGHT = 2 FEET
METHOD
 ENTER PRESSURE ALTITUDE HERE
 MOVE RIGHT TO FAT
 MOVE DOWN TO GROSS WEIGHT
 MOVE LEFT TO SKID HEIGHT
 MOVE DOWN, READ TORQUE REQUIRED
 TO HOVER = 40.6 PSIG



DATA BASIS: DERIVED FROM FLIGHT TEST USA ASTA 66-06, APRIL 1970

FIGURE 1-3. HOVER (TORQUE REQUIRED) CHART.

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CHAPTER 2

HELICOPTER AERODYNAMICS

FLIGHT THEORY

Helicopter flight theory is based on the laws of motion and pressure differential that govern the flight of all conventional heavier-than-air craft. Aviators should understand these laws in order to more easily master the helicopter aerodynamics that follow. A description of vector and scalar quantities is also included, and provides a vehicle to simplify the explanation of aerodynamics.

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NEWTON'S LAWS OF MOTION

Newton's three laws of motion are *inertia*, *acceleration*, and *action-reaction*. These laws are applicable to the flight of rotary-wing. Knowledge of the laws of motion will help aviators to understand the rotary-wing aerodynamics discussed in later sections of this chapter.

□ The first law, *inertia*, states that a body at rest will remain at rest, and a body in motion will remain in motion at the same speed and in the same direction until affected by some external force. Nothing starts or stops without an outside force to bring about or prevent motion. Hence, the force with which a body offers resistance to change is called the force of inertia.

□ The second law, *acceleration*, asserts that the force required to produce a change in motion of a body is directly proportional to its *mass* and the *rate of change* in its velocity. Acceleration may be due to an increase or a decrease in velocity, although deceleration is commonly used to indicate a decrease.

□ The third law, *action-reaction*, states that for every action there is an equal and opposite reaction. If an interaction occurs between two bodies, equal forces in opposite directions will be imparted to each body.

BERNOULLI'S PRINCIPLE

Daniel Bernoulli, one of a family of Swiss mathematicians, stated a principle that describes the relationship between internal fluid pressure and fluid velocity. His principle, essentially a statement of the conservation of energy, explains at least in

part why an airfoil develops an aerodynamic force.

All of the forces acting on a surface over which there is a flow of air are the result of *pressure* or *skin friction*. Friction forces are the result of viscosity and are confined to a very thin layer of air near the surface. They usually are not dominant, and from the pilot's perspective can be discounted with concentration instead on pressure distribution.

As an aid in visualizing what happens to pressure as air flows over an airfoil, it is helpful to consider flow through a tube (fig 2-1). The concept of conservation of mass states that mass cannot be created or destroyed; so what goes in one end of a tube must come out the other end. If the flow through a tube is neither accelerating nor decelerating at the input, then the mass of flow per unit of time at station 1 must equal the mass of flow per unit of time at station 2 and so on through station 3. The mass of flow per unit of time is called the *mass flow rate* and may be computed from the following equation:

$$\text{Mass Flow Rate} = \rho AV$$

Where: ρ (rho) = previously defined density.

A = Area of the section through which the flow is proceeding.

V = Velocity of the flow at the section in question.

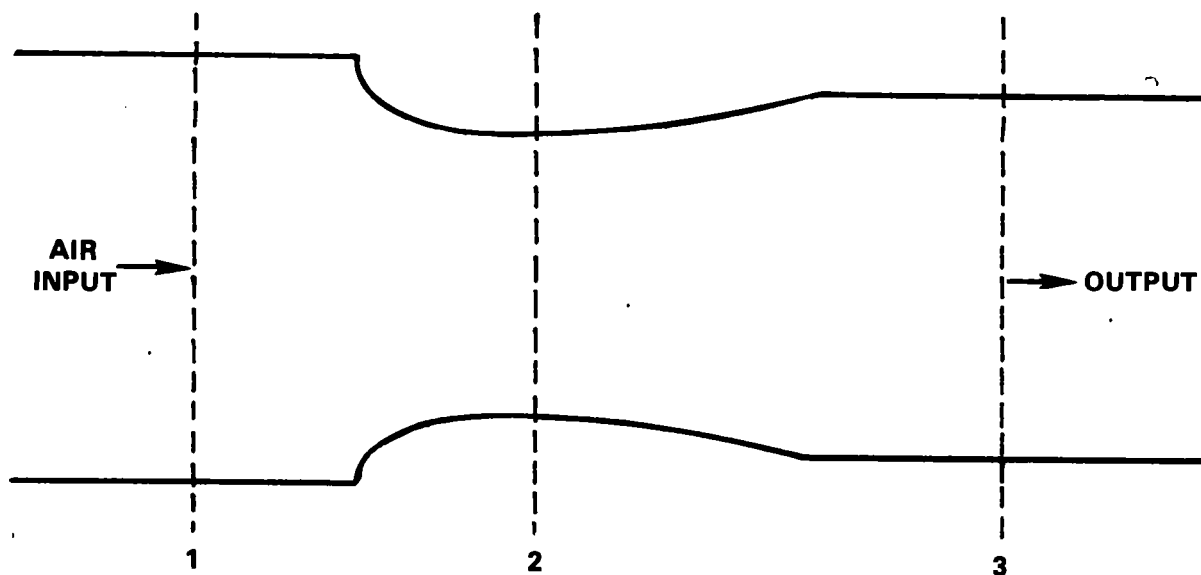
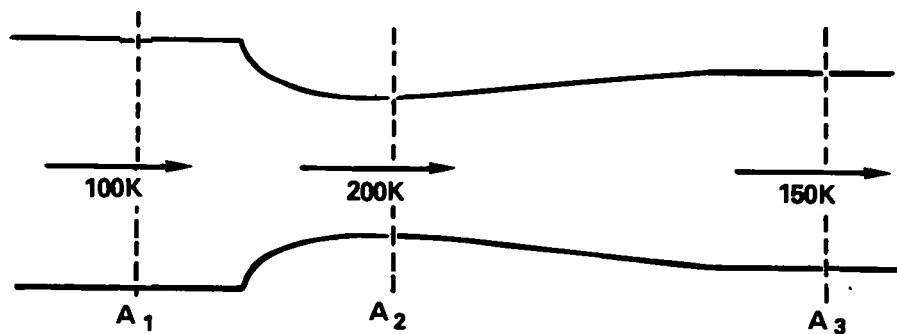


FIGURE 2-1. FLOW THROUGH A TUBE.



$$A_1 = 100 \text{ ft}^2$$

$$p_1 = 2116 \text{ psf}$$

$$q_1 = 34 \text{ psf}$$

$$H_1 = 2150 \text{ psf}$$

$$A_2 = 50 \text{ ft}^2$$

$$p_2 = 2014 \text{ psf}$$

$$q_2 = 136 \text{ psf}$$

$$H_2 = 2150 \text{ psf}$$

$$A_3 = 66.7 \text{ ft}^2$$

$$p_3 = 2072 \text{ psf}$$

$$q_3 = 78 \text{ psf}$$

$$H_3 = 2150 \text{ psf}$$

FIGURE 2-2. CHANGES OF PRESSURE AND VELOCITY WITH AREA.

The mass flow equation may be simplified in the low subsonic range because changes in density are so slight they can be neglected in all but the most precise calculations. At low flight speeds, air experiences relatively small changes in pressure and negligible changes in density. This airflow is termed incompressible, since the air may undergo changes in pressure without apparent changes in density. Such a condition of airflow is analogous to the flow of water, hydraulic fluid, or any other incompressible fluid. Thus, an equation may be written describing the flow through the stations in figure 2-1 as follows:

$$A_1 V_1 = A_2 V_2 = A_3 V_3$$

This equation suggests that between any two points in the tube, the velocity varies inversely with the area. Thus, if A_1 is greater than A_2 (as it is in fig 2-1), V_2 must be greater than V_1 . Venturi effect is the name used to describe this phenomena. Fluid flow speeds up through the restricted area of a venturi in direct proportion to the reduction in area. Figure 2-2 suggests what happens to the speed of the flow through the tube. A discussion of compressible flow and its effects is included in a later paragraph.

Total energy in a given closed system does not change, but the form of the energy may be altered. Pressure of flowing air may be likened to energy in that the total pressure of flowing air will always remain constant unless energy is added or taken from the flow. In the example in figures 2-1

and 2-2, there is no addition or subtraction of energy, so total pressure will remain constant.

Fluid flow pressure is made up of two components, static pressure, and dynamic pressure. The static pressure is the pressure that would be measured by an aneroid placed in the flow, but not moving with the flow as it measured the pressure. The dynamic pressure of the flow is that component of total pressure that is due to the motion of the air. It is difficult to measure directly, but a pitot static tube measures it indirectly. The sum of these two pressures is total pressure and is measured by allowing the flow to impact against an open end tube which is vented to an aneroid. The equation describing the sum of these pressures is written as follows:

$$H = p + q$$

where: H = total pressure

p = static pressure

q = dynamic pressure

$$q = \frac{1}{2} \rho V^2$$

The equation shown above is the incompressible or slow speed form of the Bernoulli equation. Written about the flow in figure 2-1, it would be the following:

$$H_1 = H_2 = H_3$$

or

$$p_1 + \frac{1}{2} \rho V_1^2 = p_2 + \frac{1}{2} \rho V_2^2 = p_3 + \frac{1}{2} \rho V_3^2$$

Variations of pressure and velocity with area may be seen in figure 2-2. Note that static pressure decreases as the velocity increases. Consider only the bottom half of a venturi tube as shown in figure 2-3. Notice how the shape of the restricted area at A_2 resembles the top surface of an airfoil. Even when the top half of the venturi tube is taken away, the air still accelerates over the curved shape of the bottom half. This is true because the air layers above act to restrict the flow just as did the top half of the venturi tube. As a result, acceleration causes decreased static pressure above the curved shape of the tube. A pressure differential force is generated by the local variation of static and dynamic pressures on the curved surface.

VECTOR AND SCALAR QUANTITIES

A study of helicopter flight is further enhanced by understanding two types of quantities, scalars and vectors. Scalar quantities are those that can be described by *size alone* such as area, volume, time, and mass. Vector quantities are those that must be described using their *size and direction*. Velocity, acceleration, weight, lift and drag are all common examples of vector quantities. The direction of vector quantities is just as important as the size or magnitude.

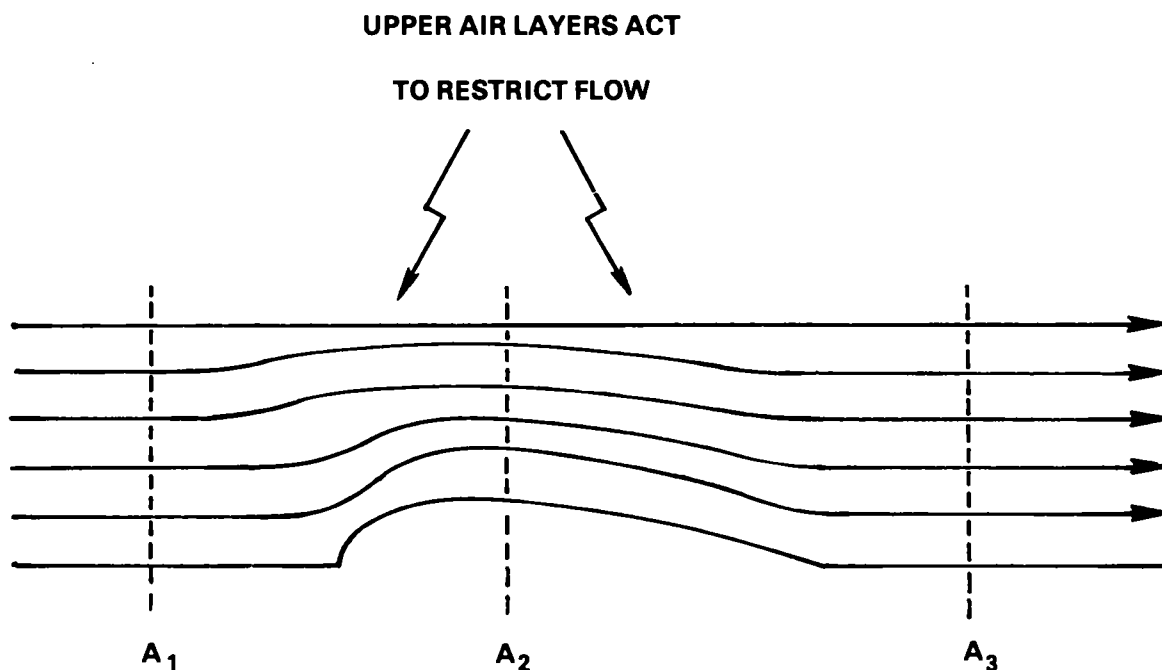


FIGURE 2-3. VENTURI FLOW.

All forces, from whatever source, are vectors. When an object is being acted upon by two or more forces, the combined effect of these forces may be represented by the use of vectors. Vectors are graphically represented by a directed line segment with an arrow at the end. The arrow indicates the direction in which the force is acting. Line segment length in relation to a given scale represents the magnitude of the force. The vector is drawn in relation to a reference line. Magnitude is drawn to whatever scale is most convenient to the specific problem (fig 2-4).

parallel to these vectors to determine the resultant mean. When two tugboats are pushing a barge with equal force, the barge will move forward in a direction that is a mean to the direction of both tugboats (fig 2-5).

□ *Polygon Vector Solution.* When more than two forces are acting in different directions, the resultant may be found by using a polygon vector solution. In the solution shown in figure 2-6, one force is acting at 090° with a force of 180 pounds;

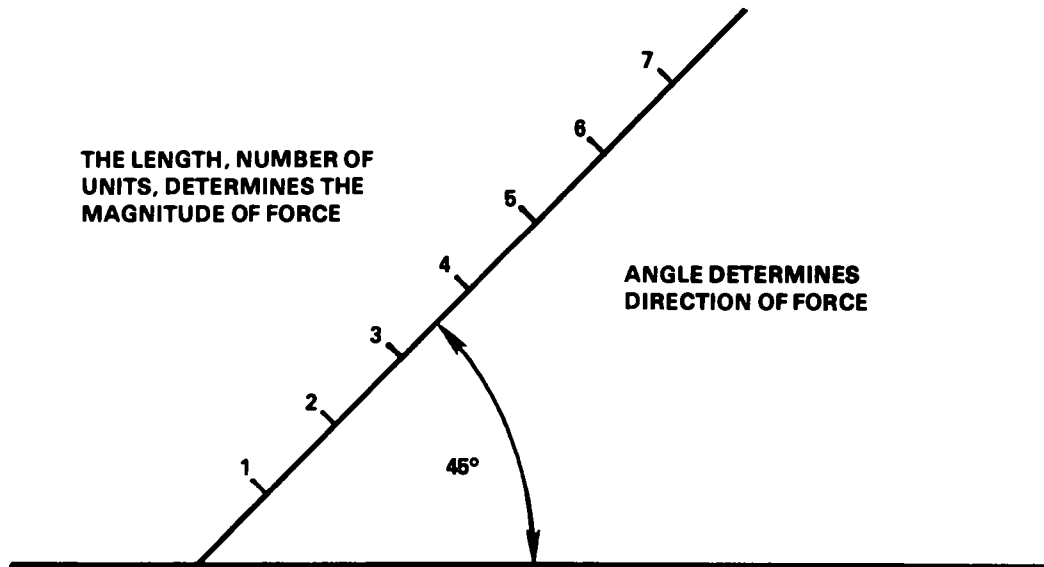


FIGURE 2-4. VECTOR DIAGRAM.

VECTOR SOLUTIONS

Individual force vectors are useful in analyzing conditions of flight. In the air, the chief concern is with the resultant, or combined effects, of the several component forces acting on an aircraft. Three methods of solving for resultants are:

□ *Parallelogram.* A parallelogram contains two vectors, and lines are drawn

second force is acting at 045° with a force of 90 pounds; the third force is acting at an angle of 315° with a force of 120 pounds. To determine the resultant, draw the first vector from a point beginning at 0 (fig 2-6) and follow it with the remaining vectors, consecutively. The resultant is drawn from the point of start (0) to the ending of the final vector (C).

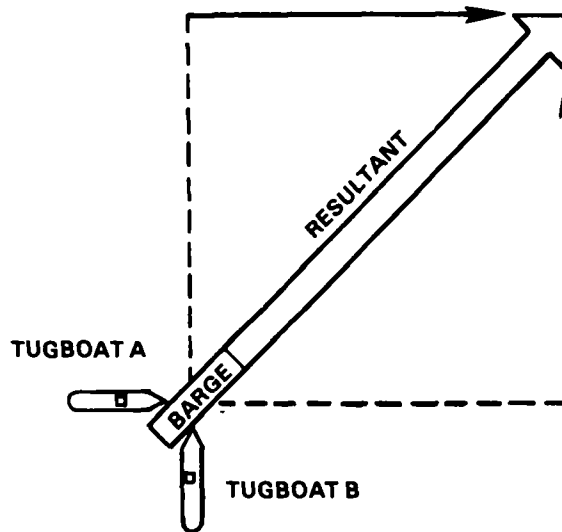


FIGURE 2-5. RESULTANT BY PARALLELOGRAM.

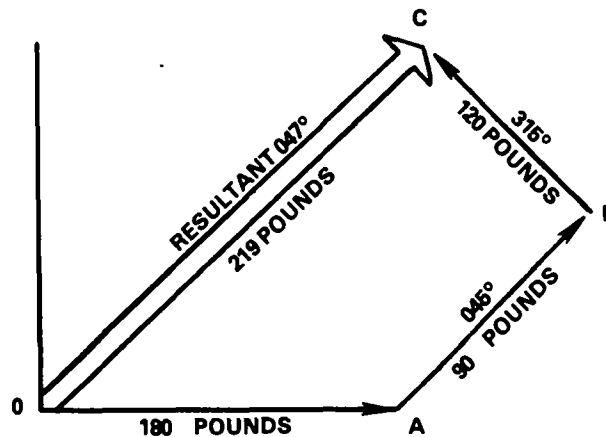


FIGURE 2-6. RESULTANT BY POLYGON.

□ *Triangle of Vectors.* A triangle of vectors is a simplified and special form of a polygon vector solution which involves only two vectors and their resultant. It is the most commonly used vector solution in navigating.

To form a triangle of vectors, draw two vectors and connect them with a resultant

line of vector. In this way, calculations may be made for drift and groundspeed. In figure 2-7, an aircraft is heading 078° with a true airspeed of 100 knots. Wind direction is from the northeast at 30 knots. By drawing a vector for each of these known velocities and drawing a connecting line between the ends, a resultant velocity is determined.

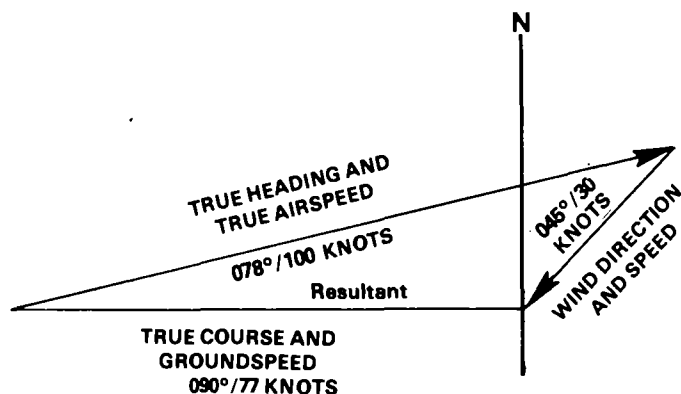


FIGURE 2-7. RESULTANT BY TRIANGULATION.

AIRFOILS

A helicopter flies for the same basic reason that any conventional heavier-than-air craft flies, because aerodynamic forces necessary to keep it aloft are produced when air passes about the rotor blades. The rotor blade, or airfoil, is the structure that makes flight possible. It is a surfaced body that produces a useful dynamic action, lift, when it passes through the air. Helicopter blades have airfoil sections designed for a specific set of flight characteristics. Some airfoil designs are less efficient under specific conditions, yet permit higher airspeeds. Other combinations of upper and lower surface designs may generate more lift, but may have a very wide center of pressure travel. Usually the designer must compromise to obtain an airfoil section that has the best flight characteristics for the mission the aircraft will perform.

Airfoil sections are of two basic types, *symmetrical* and *nonsymmetrical*. Symmetrical airfoils (fig 2-8) have identical upper and lower surfaces. They are suited to rotary-wing applications because they

have almost no center of pressure travel. Travel remains relatively constant under varying angles of attack, affording the best lift-drag ratios for the full range of velocities from rotor blade root to tip. However, the symmetrical airfoil produces less lift than a nonsymmetrical airfoil and also has relatively undesirable stall characteristics. The helicopter blade (airfoil) must adapt to a wide range of airspeeds and angles of attack during each revolution of the rotor. The symmetrical airfoil delivers acceptable performance under those alternating conditions. Other benefits are lower cost and ease of construction as compared to the nonsymmetrical airfoil.

Nonsymmetrical (cambered) airfoils (fig 2-9) may have a wide variety of upper and lower surface designs. They are currently used on some CH-47 and all OH-58 Army helicopters, and are increasingly being used on newly designed aircraft. Advantages of the nonsymmetrical airfoil are increased lift-drag ratios and more desirable stall characteristics. Nonsymmetrical airfoils

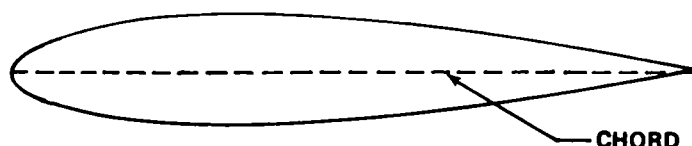


FIGURE 2-8. SYMMETRICAL AIRFOIL SECTION.

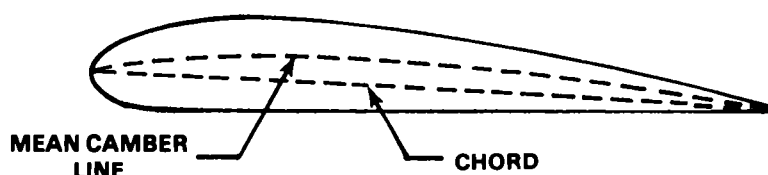


FIGURE 2-9. NONSYMMETRICAL AIRFOIL SECTION.

were not used in earlier helicopters because the center of pressure location moved too much when angle of attack was changed. When center of pressure moves, a twisting force is exerted on the rotor blades. Rotor system components had to be designed that would withstand the twisting force. Recent design processes and new materials used to manufacture rotor systems have partially overcome the problems associated with use of nonsymmetrical airfoils.

AIRFOIL SECTIONS

Rotary-wing airfoils operate under diverse conditions, because their speeds are a

combination of blade rotation and forward movement of the helicopter. An intelligent discussion of the factors affecting the magnitude of rotor blade lift and drag requires a knowledge of blade section geometry. Blades are designed with specific geometry that adapts them to the varying conditions of flight. Cross-section shapes of most rotor blades are not the same throughout the span. Shapes are varied along the blade radius to take advantage of the particular airspeed range experienced at each point on the blade, and to help balance the load between the root and tip. The blade may be built with a twist, so an airfoil section near the root has a larger pitch angle than a section near the tip.

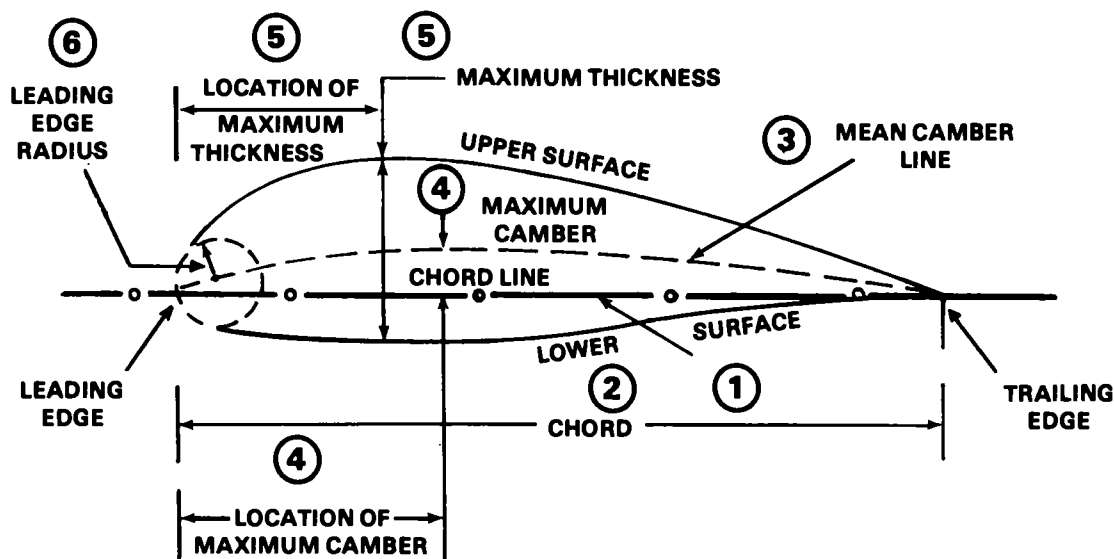


FIGURE 2-10. AIRFOIL TERMINOLOGY.

Figure 2-10 illustrates a typical airfoil section and defines the various items of airfoil terminology.

① The *chord line* is a straight line connecting the leading and trailing edges of the airfoil.

② The *chord* is the length of the chord line from leading edge to trailing edge and is the characteristic longitudinal dimension of the airfoil.

③ The *mean camber line* is a line drawn halfway between the upper and lower surfaces. The chord line connects the ends of the mean camber line.

④ The shape of the mean camber is important in determining the aerodynamic characteristics of an airfoil section. *Maximum camber* (displacement of the mean

camber line from the chord line) and the location of maximum camber help to define the shape of the mean camber line. These quantities are expressed as fractions or percentages of the basic chord dimension.

⑤ Thickness and thickness distribution of the profile are important properties of an airfoil section. The *maximum thickness* and its *location* help define the airfoil shape and are expressed as a percentage of the chord.

⑥ The *leading edge radius* of the airfoil is the radius of curvature given the leading edge shape.

ROTARY-WING PLANFORM

Common terms used to describe the helicopter rotor system are shown in figures 2-11 and 2-12. Although there is some variation in systems between different aircraft, the terms shown are generally

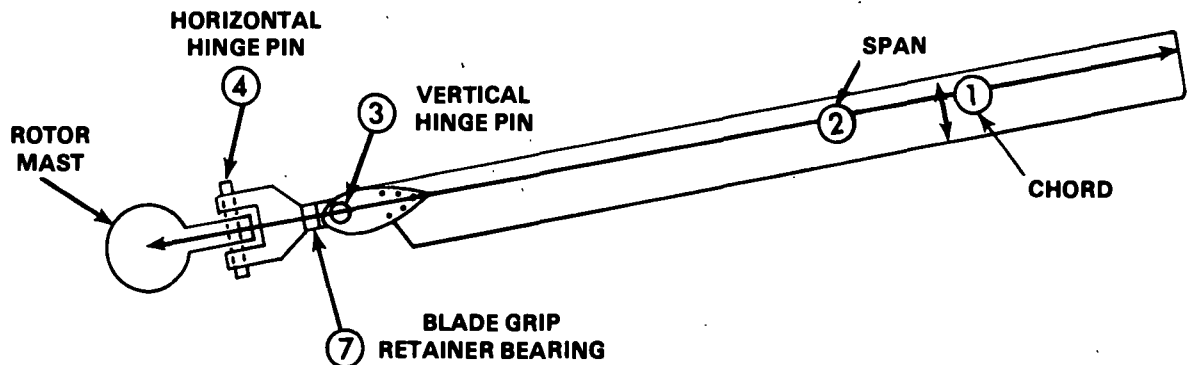


FIGURE 2-11. FULLY ARTICULATED ROTOR SYSTEM.

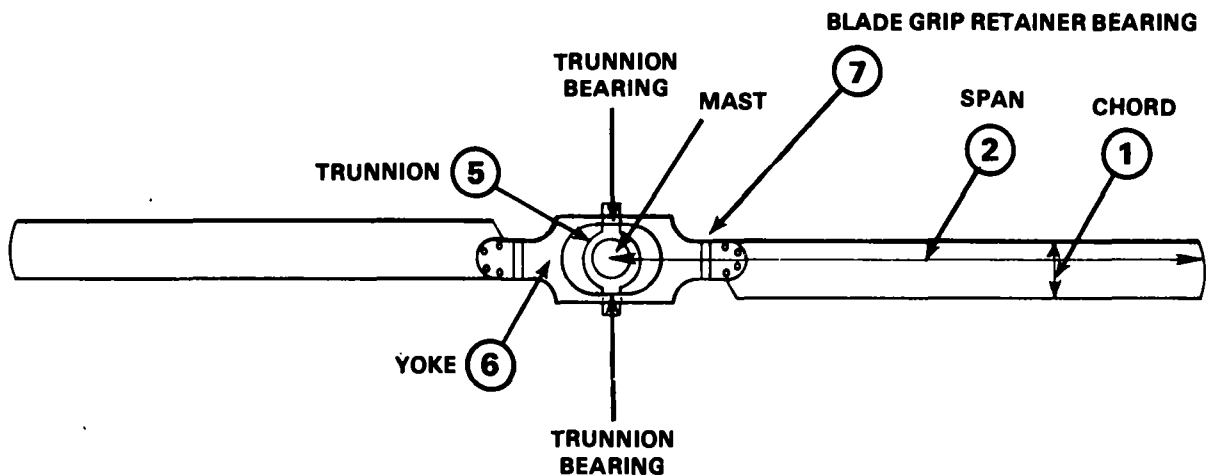


FIGURE 2-12. SEMIRIGID ROTOR SYSTEM.

accepted by most manufacturers. The system shown in figure 2-11 is fully articulated. Semirigid types (fig 2-12) do not have a vertical or horizontal hinge pin. Instead the rotor is allowed to teeter or flap by a trunnion bearing that connects the yoke to the mast.

① The *chord* is the longitudinal dimension of an airfoil section, measured from the leading edge to the trailing edge.

② The *span* is the length of the rotor blade from the point of rotation to the tip of the blade.

③ The *vertical hinge pin* (drag hinge) is the axis which permits fore and aft blade movement independent of the other blades in the system.

④ The *horizontal hinge pin* is the axis which permits up and down movement of the blade independent of the other blades in the system.

⑤ The *trunnion* is splined to the mast and has two bearings through which it is secured to the yoke ⑥. The blades are mounted to the yoke and are free to teeter (flap) about the trunnion bearings.

⑥ The *yoke* is the structural member to which the blades are attached and which fastens the rotor blades to the mast through the trunnion and trunnion bearings.

⑦ The *blade grip retainer bearing* is the bearing which permits rotation of the blade

about its spanwise axis, so blade pitch can be changed (blade feathering).

Blade twist is a characteristic built into the rotor blade so angle of incidence is less near the tip than at the root. Blade twist helps distribute the lift evenly along the blade by an increased angle of incidence near the root where blade speed is slower. Outboard portions of the blade that travel faster normally have lower angles of incidence, so less lift is concentrated near the blade tip.

RELATIVE WIND

A knowledge of relative and wind is particularly essential for an understanding of aerodynamics of rotary-wing flight because relative wind may be composed of multiple components. Relative wind is defined as the airflow relative to an airfoil and is illustrated in figure 2-13.

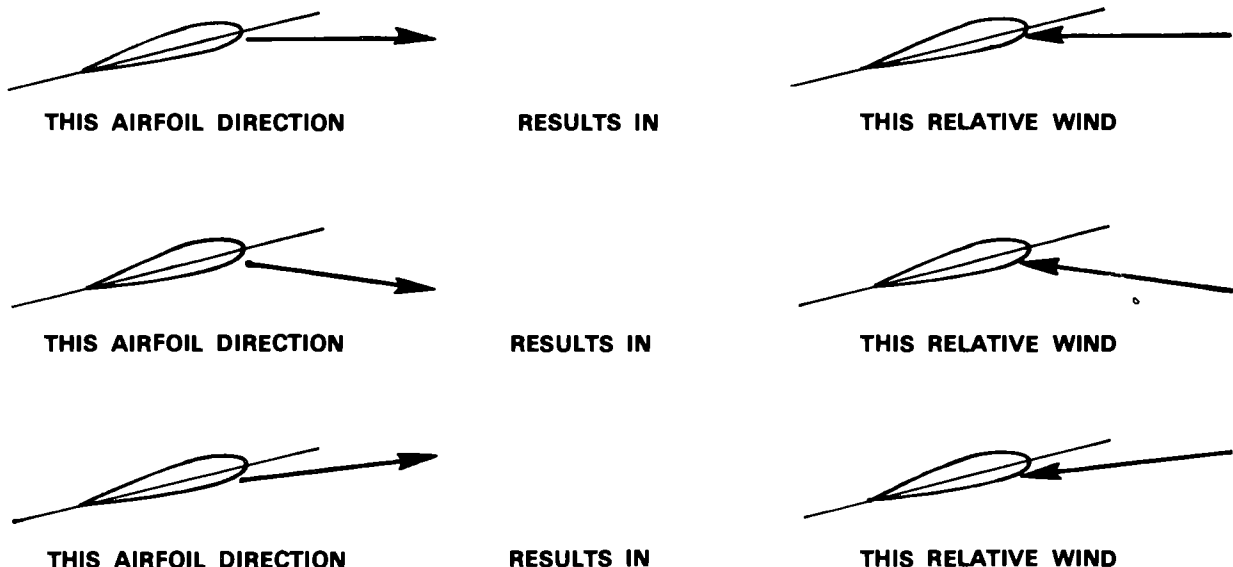


FIGURE 2-13. RELATIVE WIND.

Relative wind is created by movement of an airfoil through the air. As an example, consider a person sitting in an automobile on a no-wind day with a hand extended out the window. There is no airflow about the hand since the automobile is not moving. However, if the automobile is driven at 50 miles per hour, the air will flow under and over the hand at 50 miles per hour. A relative wind has been created by moving the hand through the air. Relative wind flows in the opposite direction that the hand is moving. The velocity of airflow around the hand in motion is the hand's airspeed.

When the helicopter is stationary on a no-wind day, *rotational relative wind* is produced by rotation of the rotor blades. Since the rotor is moving horizontally, the effect is to displace some of the air downward. The blades travel along the same path and pass a given point in rapid succession (a three-bladed system rotating at 320 revolutions per minute (RPM) passes a blade by a given point in the tip-path plane 16 times per second). Figure

2-14 illustrates how still air is changed to a column of descending air by rotor blade action. This flow of air is called an *induced flow* (downwash). It is most predominant at a hover under still wind conditions. Because the rotor system circulates the airflow down through the rotor disk, the rotational relative wind (A, fig 2-15) is modified by the induced flow. Airflow from rotation, modified by induced flow, produces the *resultant relative wind* (D, fig 2-15). In the example shown in D, figure 2-15, angle of attack is reduced by induced flow, causing the airfoil to produce less lift.

When the helicopter has horizontal motion, the resultant relative wind discussed above is further changed by the helicopter airspeed. Airspeed component of relative wind results from the helicopter moving through the air. It is added to or subtracted from the rotational relative wind, depending on whether the blade is advancing or retreating in relation to helicopter movement (B and C, fig 2-15). Induced flow is also modified by introduction of airspeed relative wind. The pattern

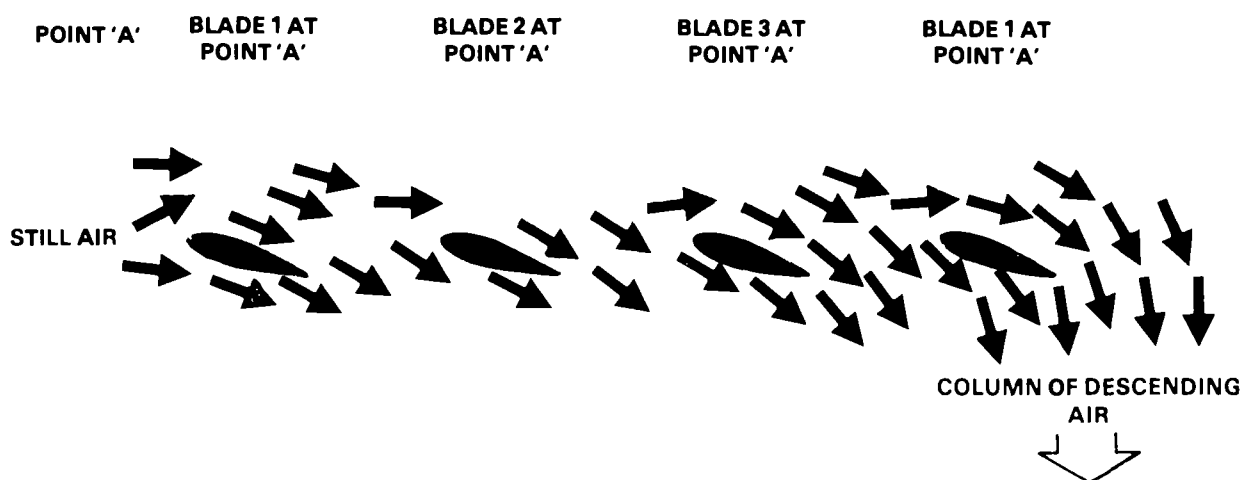


FIGURE 2-14. INDUCED FLOW (DOWNWASH).

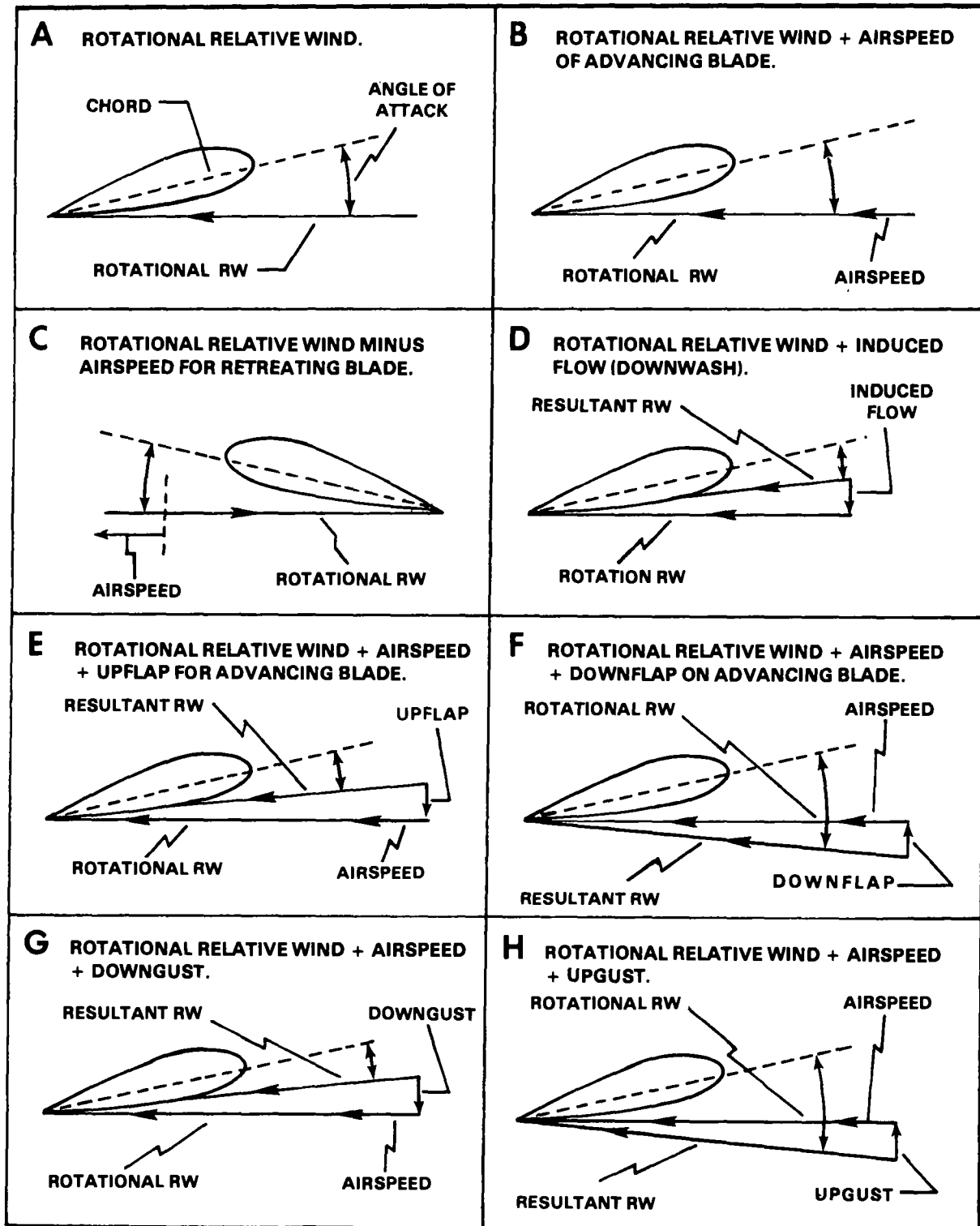


FIGURE 2-15. COMPONENTS OF RELATIVE WIND (RW).

of air circulation through the disk changes when the aircraft has movement. Generally the downward velocity of induced flow is reduced. The helicopter moves continually into an undisturbed airmass, resulting in less time to develop a vertical airflow pattern. As a result, additional lift is produced from a given blade pitch setting. The effects of blade flapping and wind gusts on the relative wind are illustrated in E, F, G, and H (fig 2-15).

ANGLE OF ATTACK

Angle of attack is an *aerodynamic angle* and is illustrated by ④, figure 2-16. It is defined as the angle between the airfoil chord and its direction of motion relative to

the air (resultant relative wind). Several factors may cause rotor blade angle of attack to change. Some are controlled by the pilot and some occur automatically due to the rotor system design. Pilots are able to adjust angle of attack by moving the cyclic and collective pitch controls. However, even when these controls are held stationary, the angle of attack constantly changes as the blade moves about the circumference of the rotor disk. Other factors affecting angle of attack, over which the pilot has little control, are blade flapping, blade flexing, and gusty wind or turbulent air conditions. Angle of attack is one of the primary factors that determines amount of lift and drag produced by an airfoil.

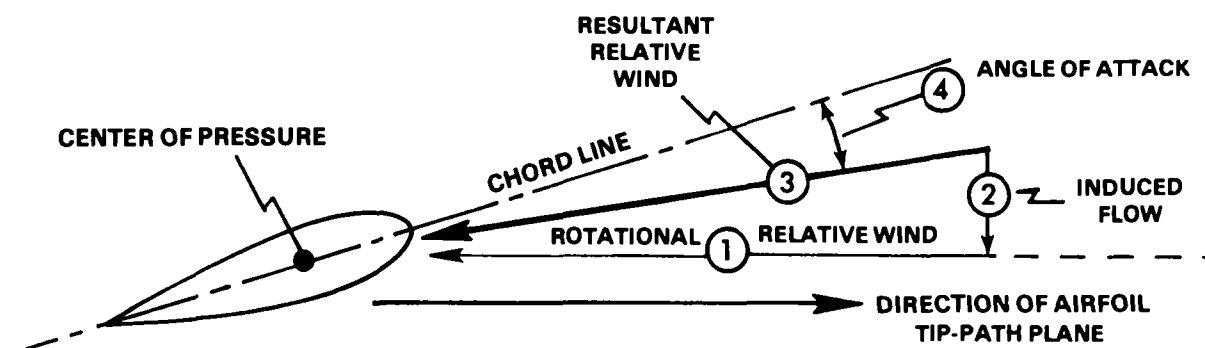


FIGURE 2-16. ANGLE OF ATTACK.

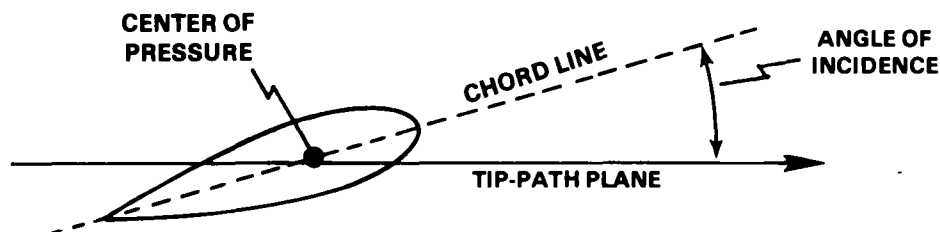


FIGURE 2-17. ANGLE OF INCIDENCE.

Angle of attack should not be confused with angle of incidence (blade pitch angle). Angle of incidence is the angle between the blade chord line and the plane of rotation of the rotor system (fig 2-17). It is a *mechanical angle* rather than an *aerodynamic angle*. In the absence of induced flow and/or aircraft airspeed, angle of attack and angle of incidence are the same. Whenever relative wind is modified by induced flow or aircraft airspeed, then angle of attack is different than angle of incidence.

TOTAL AERODYNAMIC FORCE

A total aerodynamic force is generated when a stream of air flows over and under an airfoil that is moving through the air. The point at which the air separates to flow about the airfoil is called the point of impact (fig 2-18). A high pressure area or

stagnation point is formed at the point of impact. Normally the high pressure area is located at the lower portion of the leading edge, depending on angle of attack. The high pressure area contributes to the overall force produced by the blade.

Figure 2-18 also shows airflow lines that illustrate how the air moves about the airfoil section. Notice that the air is deflected downward as it passes under the airfoil and leaves the trailing edge. Remember Newton's third law which states, "every action has an equal and opposite reaction." Since the air is being deflected downward, an equal and opposite force must be acting upward on the airfoil. This force adds to the total aerodynamic force developed by the airfoil. At very low or zero angles of attack, the deflection force or impact pressure may exert a zero positive force or even a downward or negative force.

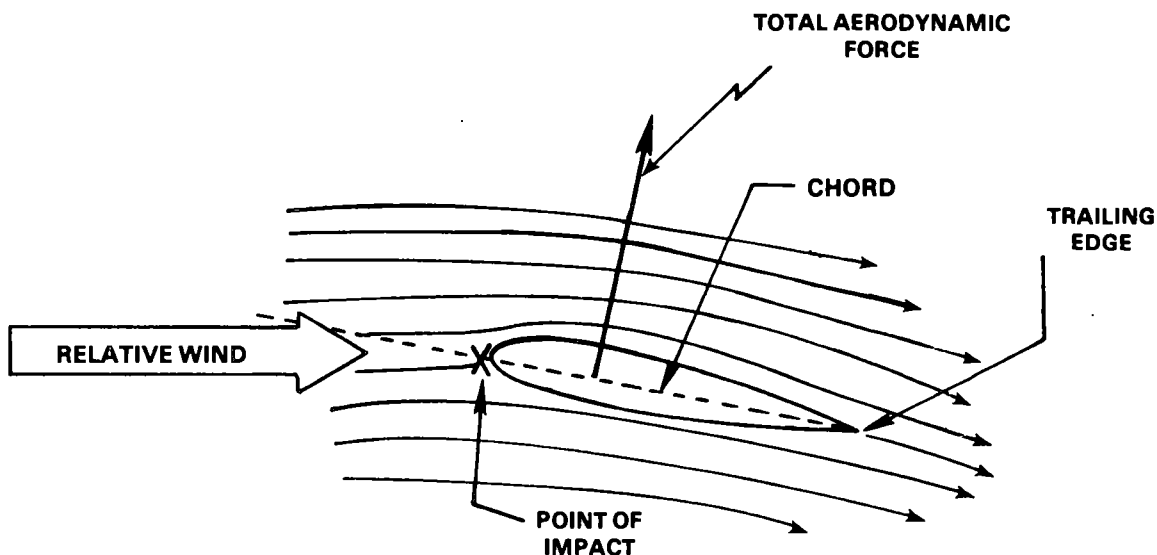


FIGURE 2-18. AIRFLOW AROUND AN AIRFOIL.

Air passing over the top of the airfoil produces aerodynamic force in another way. In figure 2-18, the distance is longer from the point of impact over the top of the airfoil to the trailing edge than the distance from the point of impact to the trailing edge measured under the airfoil. The air traveling over the top must travel further in about the same time as the air traveling under the airfoil. To do this, the air passing over the top must accelerate and travel at a greater velocity. The mass flow equation, already discussed in the section on Bernoulli's Principle, established that pressure and velocity are inversely proportional. Therefore, the increase in velocity causes a decrease in pressure on top of the airfoil and exerts an upward aerodynamic force. Pressure differential between the upper and lower surface of the airfoil is quite small—in the vicinity of 1 percent. Even a small pressure differential produces substantial force when applied to a large area of rotor blade.

The total aerodynamic force, sometimes called the resultant force, may be divided into two components called lift and drag. *Lift* acts on the airfoil in a direction perpendicular to the relative wind and is illustrated by the vector labeled ① (fig 2-19). *Drag* is the resistance or force that opposes the motion of the airfoil through the air. It acts on the airfoil in a direction parallel to the relative wind. Drag is illustrated by the vector labeled ② in figure 2-19.

Many factors contribute to the total lift produced by an airfoil. Increased speed causes increased lift because a larger pressure differential is produced between the upper and lower surfaces. Lift does not increase in direct proportion to speed, but varies as the square of the speed. Thus, a blade traveling at 500 knots has four times the lift of the same blade traveling at only 250 knots. Lift also varies with the area of the blades. A blade area of 100 square feet

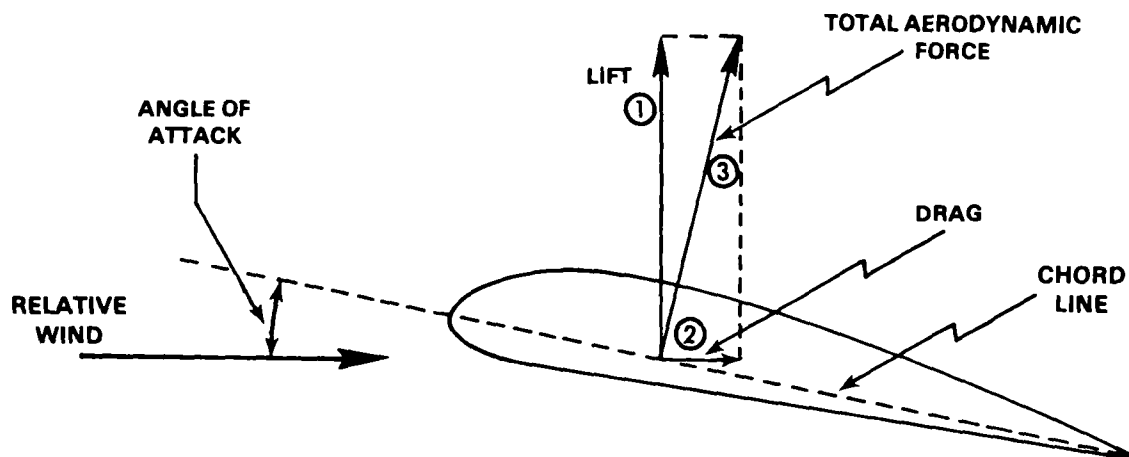


FIGURE 2-19. FORCES ACTING ON AN AIRFOIL.

will produce twice as much lift as a blade area of only 50 square feet. Angle of attack also has an effect on the lift produced. Lift increases as the angle of attack increases up to the stalling angle of attack. Stall angle varies with different blades and is the point at which airflow no longer follows the camber of the blade smoothly. Camber or shape of the airfoil also has an effect on lift as already discussed in the section on airfoils. Air density is another factor that directly influences lift as covered in the section on properties of the atmosphere. Aviators should consult aircraft performance charts in chapter 7 of the aircraft Operator's Manual to determine how aircraft performance is affected by given air density conditions.

Two design factors, *airfoil shape* and *airfoil area*, are primary elements that determine how much lift and drag a blade will produce. Any change in these design factors will affect the forces produced. This can best be seen by examination of the following equations:

□ Lift Equation: $L = C_L q S$

$$L = C_L \frac{1}{2} \rho V^2 S$$

Where: L = Lift in pounds

C_L = Coefficient of lift

ρ = Density of air in slugs/
cubic feet

S = Total blade area in
square feet

V = Airspeed in feet per
second

q = Dynamic pressure

□ Drag Equation: $D = C_D q S$

$$D = C_D \frac{1}{2} \rho V^2 S$$

Where: D = Drag in pounds

C_D = Coefficient of drag

ρ = Density of air in slugs/
cubic feet

S = Total blade area in
square feet

V = Airspeed in feet per
second

q = Dynamic pressure

NOTE: C_L and C_D are pure numbers (dimensionless) and are indicative of the efficiency of an airfoil. They are determined from wind tunnel tests and their values vary with different types of airfoils and different angles of attack.

Normally an increase in lift will also produce an increase in drag. Therefore, the airfoil is designed to produce the most lift and the least drag within normal speed ranges. Figure 2-20 shows how lift and drag increase with angle of attack for one type of airfoil. The line labeled L/D shows how the lift/drag ratio varies with different angles of attack.

PRESSURE PATTERNS

Distribution of pressure over an airfoil section may be a source of an aerodynamic twisting force as well as lift. A typical example is illustrated by the pressure distribution pattern developed by the cambered (nonsymmetrical) airfoil in figure 2-21. The upper surface has pressures distributed which produce the upper sur-

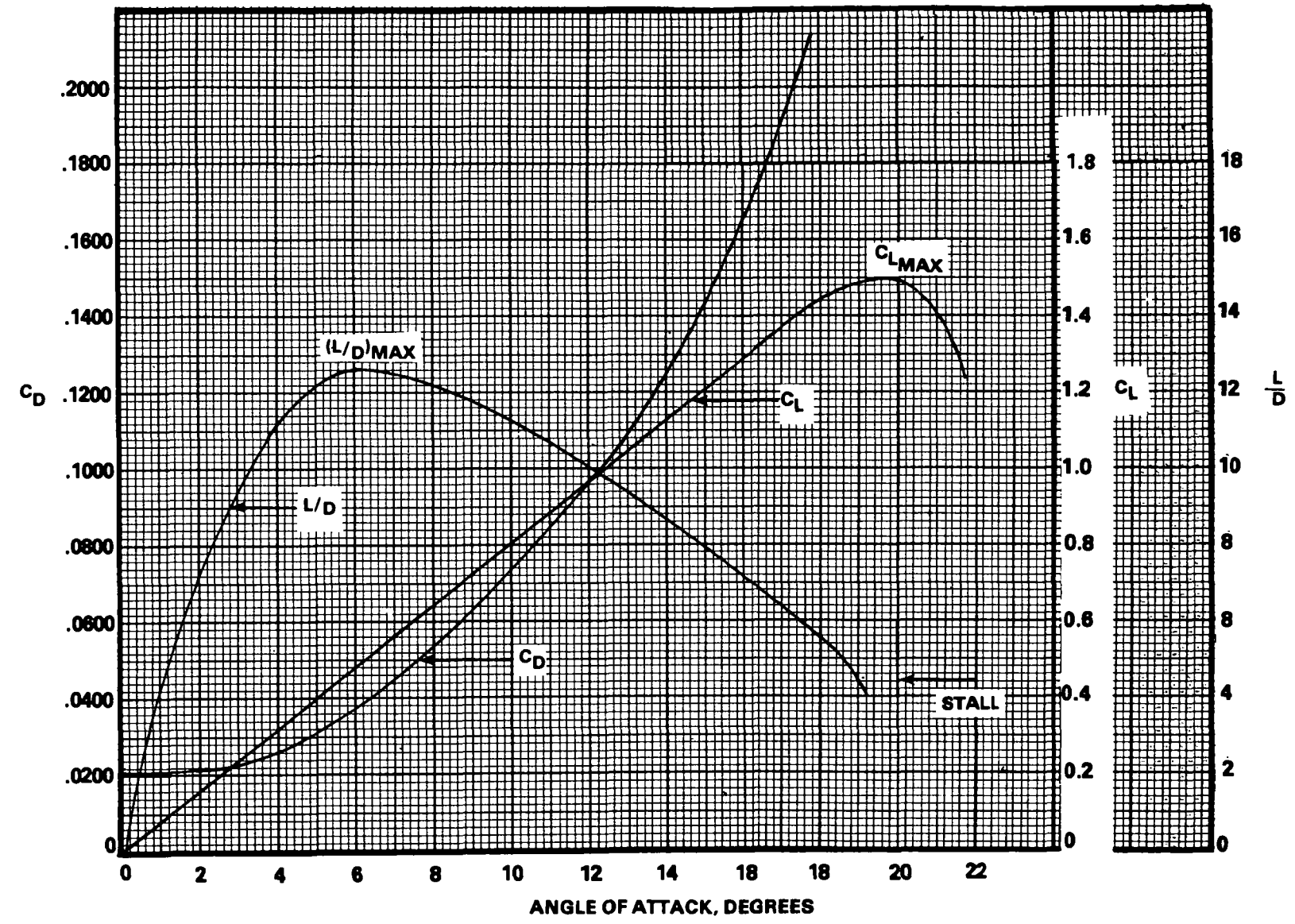


FIGURE 2-20. LIFT-DRAGE RELATIONSHIP.

face lift. The lower surface has pressures distributed which produce the lower surface force. Net lift produced by the airfoil is the difference between lift on the upper surface and the force on the lower surface. Net lift is effectively concentrated at a point on the chord called the *center of pressure*.

When angle of attack is increased (B, fig 2-21), upper surface lift increases relative to the lower surface force. Since the two vectors are not located at the same point along the chord line, a twisting force is exerted about the center of pressure. Center of pressure also moves along the chord line when angle of attack changes, because the two vectors are separated. This characteristic of nonsymmetrical airfoils results in undesirable control forces that must be compensated for if the airfoil is used in rotary-wing applications.

Pressure patterns for symmetrical airfoils are distributed differently than for nonsymmetrical airfoils (fig 2-22). Upper and lower surface vectors are opposite each other instead of being separated along the chord line as in the cambered airfoil in figure 2-21. When the angle of attack is increased to develop positive lift, the vectors remain essentially opposite each other and the twisting force is not exerted. Center of pressure remains relatively constant even when angle of attack is changed. This is a desirable characteristic for a rotor blade, because it changes angle of attack constantly during each revolution.

DRAG

Drag is the force that opposes the motion of an aircraft through the air. *Total drag* produced by an aircraft is the sum of the *profile drag*, *induced drag*, and *parasite drag* described below. Total drag is primarily a function of airspeed. The airspeed that produces the lowest total drag normally determines the aircraft best-rate-of-climb speed, minimum rate-of-descent speed for autorotation, and maximum endurance speed. Figure 2-23 illustrates the interrelationship of these factors.

□ *Profile drag* is the drag incurred from frictional resistance of the blades passing through the air. It does not change significantly with angle of attack of the airfoil section, but increases moderately as airspeed increases.

□ *Induced drag* is that drag incurred as a result of production of lift. Higher angles of attack which produce more lift also produce increased induced drag. In rotary-wing aircraft, induced drag decreases with increased aircraft airspeed.

□ *Parasite drag* is that drag incurred from the nonlifting portions of the aircraft. It includes the form drag and skin friction associated with the fuselage, cockpit, engine cowlings, rotor hub, landing gear, and tail boom. Parasite drag increases with airspeed.

OPEN FOR
FOLDOUT



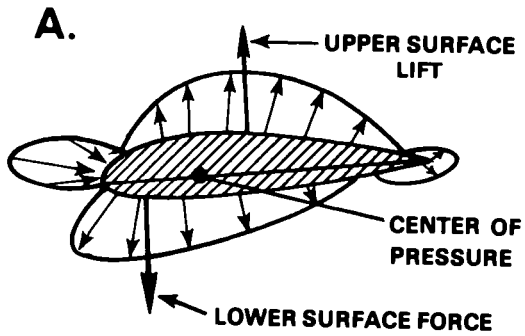
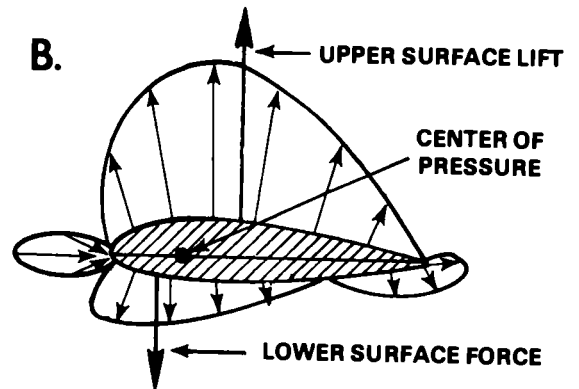
CAMBERED AIRFOIL
AT ZERO LIFTCAMBERED AIRFOIL
AT POSITIVE LIFT

FIGURE 2-21. CAMBERED AIRFOIL PRESSURE PATTERNS.

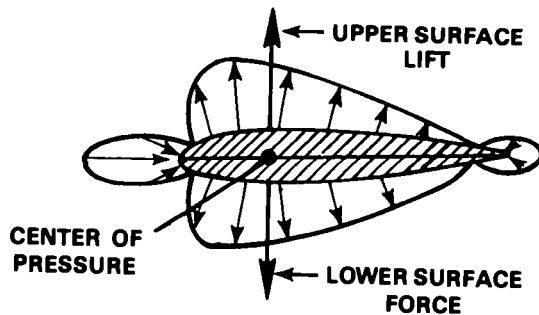
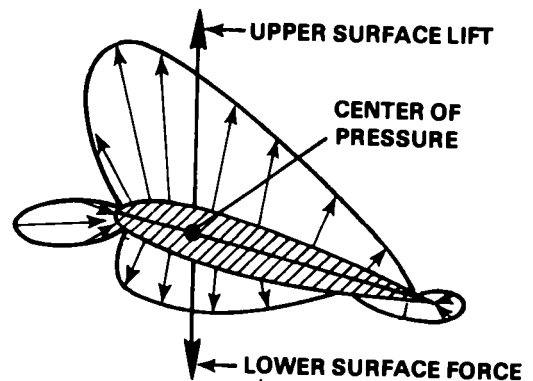
SYMMETRICAL AIRFOIL
AT ZERO LIFTSYMMETRICAL AIRFOIL
AT POSITIVE LIFT

FIGURE 2-22. SYMMETRICAL AIRFOIL PRESSURE PATTERNS.

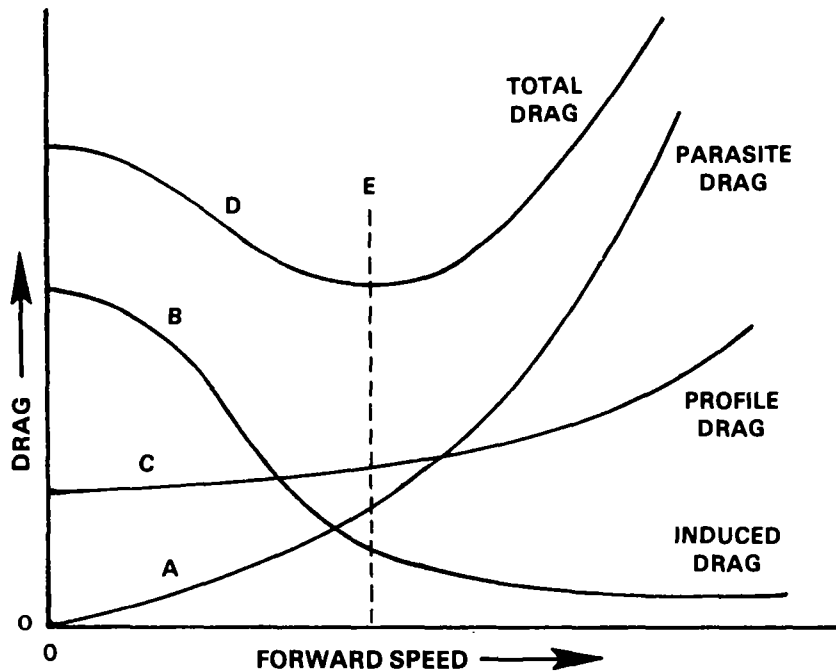


FIGURE 2-23. DRAG/AIRSPEED RELATIONSHIP.

- Curve A shows that parasite drag is very low at slow airspeeds and increases with higher airspeeds. Parasite drag goes up at an increasing rate at airspeeds above the midrange.

- Curve B illustrates how induced drag decreases as aircraft airspeed increases. At a hover, or at lower airspeeds, induced drag is highest. It decreases as airspeed increases and the helicopter moves into undisturbed air.

- Curve C shows the profile drag curve. Profile drag remains relatively constant throughout the speed range with some increase at the higher airspeeds.

- Curve D shows total drag and represents the sum of the other three curves. It identifies the airspeed range, line E, at which total drag is lowest. That airspeed is the best airspeed range for maximum endurance, best rate of climb, and minimum rate of descent in autorotation.

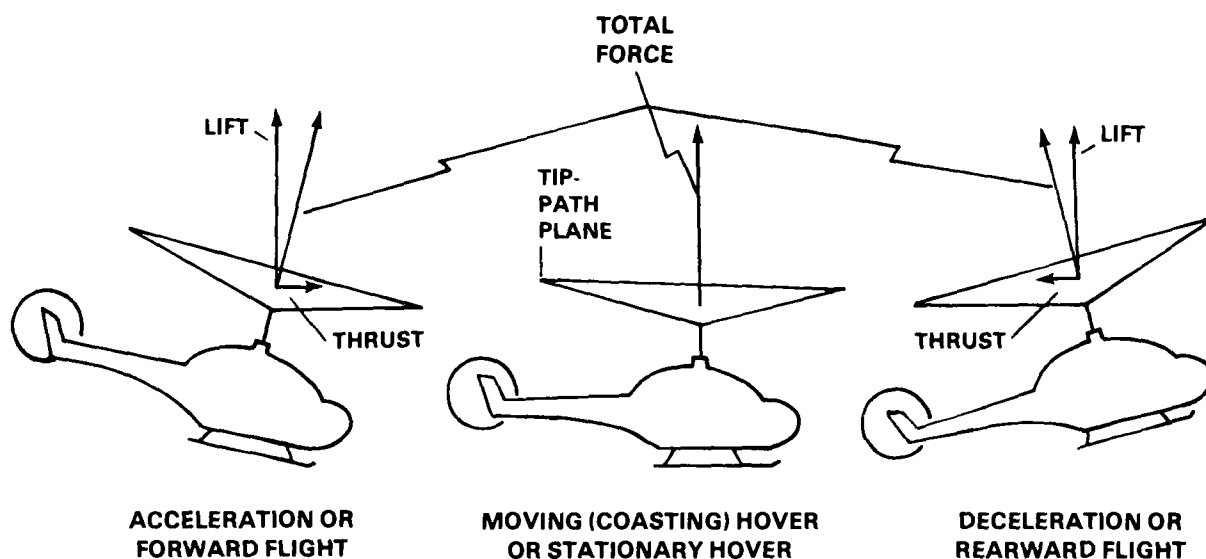


FIGURE 2-24. TOTAL FORCE IS PERPENDICULAR TO TIP-PATH PLANE.

BALANCE OF FORCES

Newton's second law is probably one of the most important principles governing helicopter motion. It states that the rate of change of motion of a body is directly proportional to the applied unbalanced force, and inversely proportional to the body's mass. This means that motion is started, stopped, or changed by causing the forces acting on the body to be unbalanced. Rate of change (acceleration) depends on the magnitude of the unbalanced force and on the mass of the body to which it is applied. Applying this principle

to a helicopter provides the basis for all helicopter flight—vertical, forward, backward, sideward, or hovering. In each case, the *total force* generated by a rotor system is always *perpendicular to the tip-path plane*. For convenience this force is divided into two components—*lift* and *thrust*. The lift component acts to support aircraft weight. The thrust component acts horizontally to accelerate or decelerate the helicopter in the desired direction. Pilots may direct the thrust in the desired direction by tilting the tip-path plane (fig 2-24).

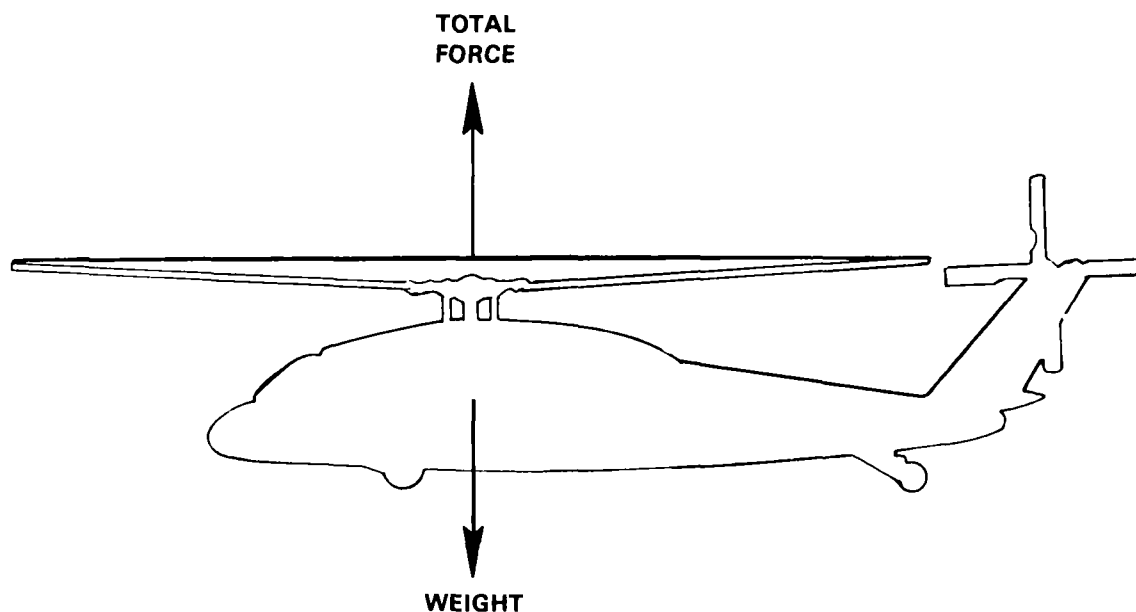


FIGURE 2-25. BALANCED FORCES, HELICOPTER HOVERING, NO WIND.

At a hover in a no-wind condition, all opposing forces are in balance and the helicopter remains stationary (fig 2-25). The total force is acting opposite to the aircraft weight. To make the helicopter move in some direction, a force must be applied to cause an unbalanced condition. Figure 2-26 shows the unbalanced condition. The pilot has changed the attitude of the rotor disk so there is a lift vector and a thrust vector which results in a total force that is forward of the vertical. No parasite drag is shown because the aircraft has not started to move forward. As the aircraft begins to move (accelerate) in the direction of the applied force (thrust), it begins to develop parasite drag. When parasite drag increases enough and is equal to the thrust,

the body will no longer accelerate because the forces are again in balance (fig 2-27). The aircraft continues to move in the new direction at the new speed until some other unbalance of force is applied to change the motion.

If the pilot wants to return to a hover condition, the aircraft attitude is changed so the thrust vector is smaller than parasite drag, or directed to the rear as shown in figure 2-28. Thrust and parasite drag now act opposite the forward motion so an unbalance of forces exists. The helicopter will decelerate until all motion is stopped. To remain stopped, the pilot must adjust aircraft attitude to balance the forces as shown in figure 2-25.

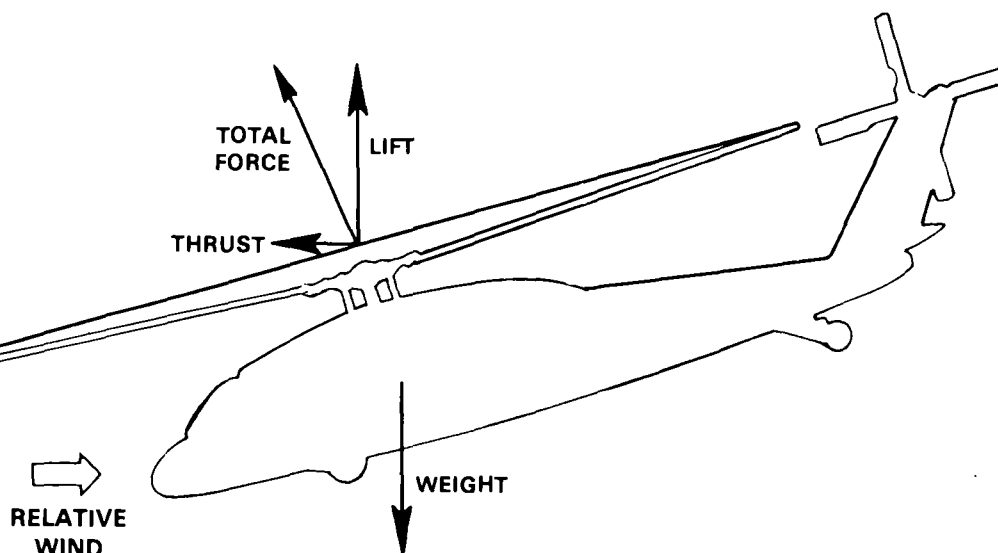


FIGURE 2-26. UNBALANCED FORCES CAUSING ACCELERATION.

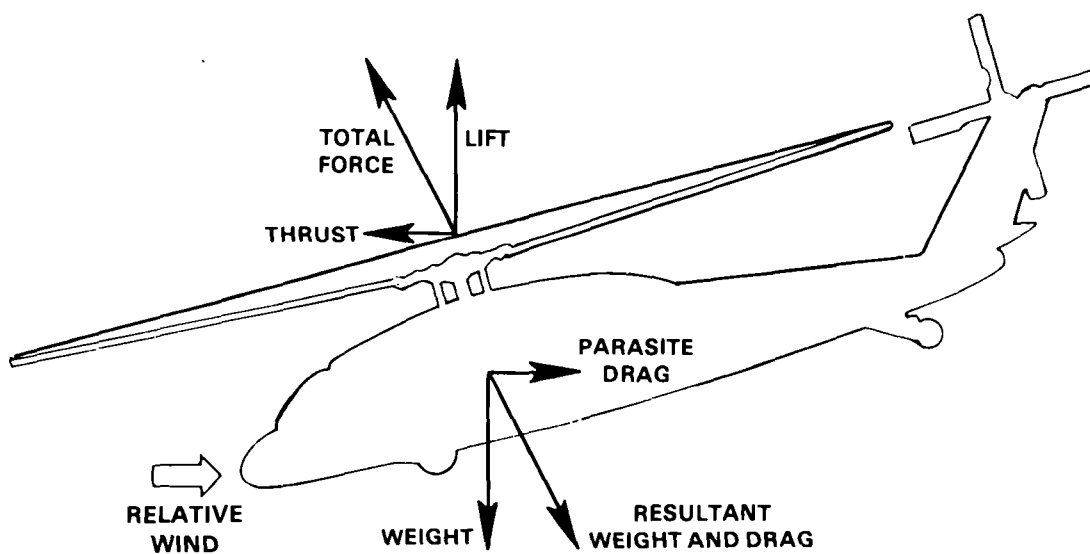


FIGURE 2-27. BALANCED FORCES, AIRCRAFT IN MOTION.

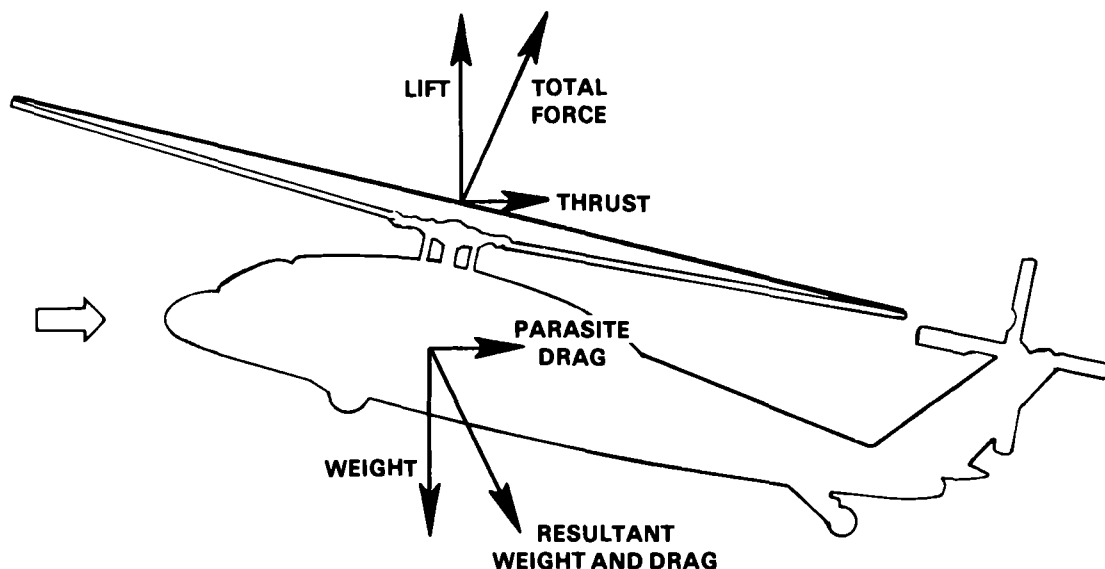


FIGURE 2-28. UNBALANCED FORCES CAUSING DECELERATION.

CENTRIFUGAL FORCE

Helicopter rotor systems depend primarily on rotation to produce relative wind which develops the aerodynamic force required for flight. Because of its rotation and weight, the rotor system is subject to forces and moments peculiar to all rotating masses. One of the forces produced is *centrifugal force*. It is defined as the force that tends to make rotating bodies move away from the center of rotation. Another force produced in the rotor system is *centripetal force*. It is the force that counteracts centrifugal force by keeping an object a certain radius from the axis of rotation.

The rotating blades of a helicopter produce very high centrifugal loads on the rotor head and blade attachment assemblies. As a matter of interest, centrifugal loads may be from 6 to 12 tons at the blade root of two to four passenger helicopters. Larger helicopters may develop up to 40 tons of centrifugal load on each blade root. In rotary-wing aircraft, centrifugal force is the dominant force affecting the rotor system. All other forces act to modify this force.

When the rotor blades are at rest, they droop due to their weight and span. In fully articulated systems, they rest against a static or droop stop which prevents the

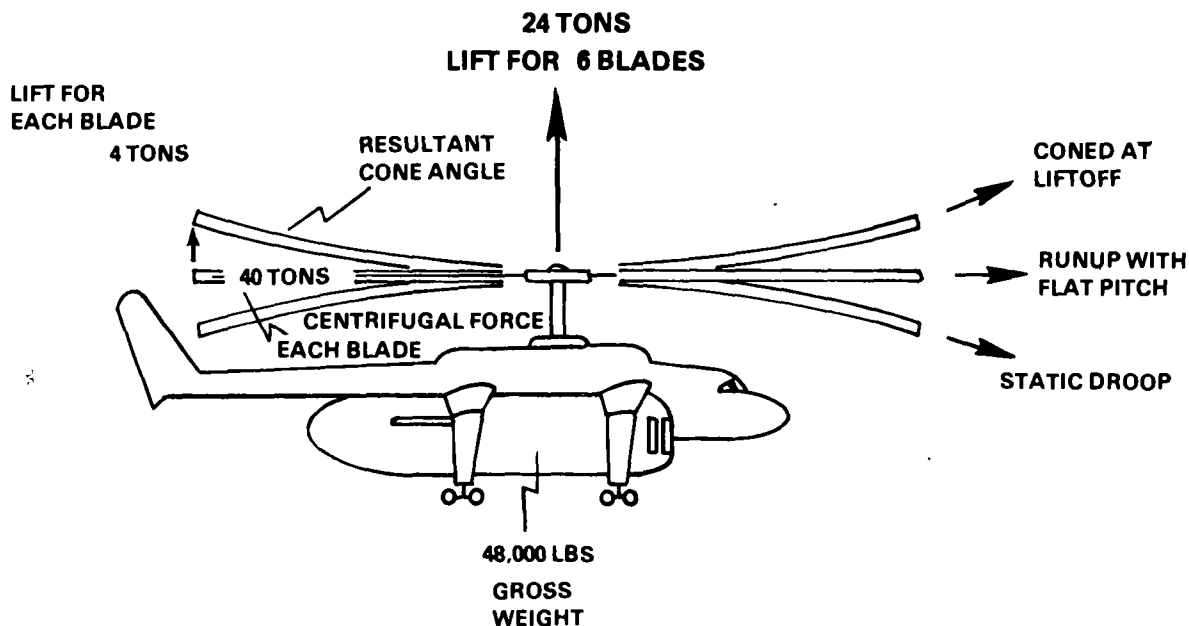


FIGURE 2-29. FLEXIBLE ROTOR BLADES SUPPORTING HEAVY LOAD.

blade from descending so low it will strike the aircraft (fig 2-29). When the rotor system begins to turn, the blade starts to rise from the static position because of centrifugal force. At operating speed, the blades extend straight out even though they are at flat pitch and are not producing lift (fig 2-29).

As the helicopter develops lift during takeoff and flight, the blades rise above the "straight out" position and assume a *coned* position (fig 2-29). Amount of coning depends on RPM, gross weight, and G-forces experienced during flight. If RPM is held constant, coning increases as gross weight and G-force increase. If gross

weight and G-forces are constant, decreasing RPM will also cause increased coning. Excessive coning can occur if RPM gets too low, gross weight is too high, or if excessive G-forces are experienced. Excessive coning can cause undesirable stresses on the blade and a decrease of total lift because of a decrease in effective disk area (fig 2-30). Notice that the effective diameter of the rotor disk with increased coning (A, fig 2-30) is less than the diameter of disk B with less coning. A smaller disk diameter has less potential to produce lift.

Centrifugal force and lift effects on the blade can be illustrated best by a vector. Figure 2-31 shows a rotor shaft and vector

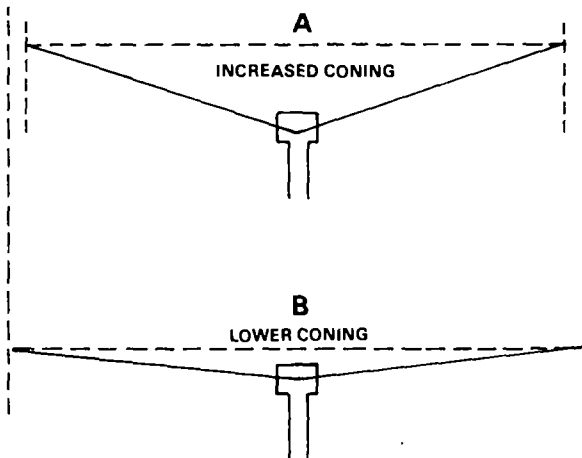


FIGURE 2-30. LOSS OF DISK AREA DUE TO CONING.

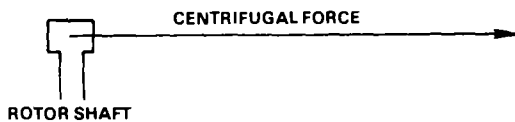


FIGURE 2-31. CENTRIFUGAL FORCE.

resulting from rotation of a blade. Figure 2-32 shows a vertical force vector acting at the blade tip. This vertical force is lift produced when the blades assume a positive angle of attack. The blade is no longer being acted upon solely by centrifugal force. It is also producing lift which is manifested at the blade tip by the lift vector. Since one end of the blade is attached to the rotor shaft, it is not free to move. The other end can move and will assume a position that is a resultant of the forces (vectors) acting on it (fig 2-33). The blade position is coned and is a resultant of two forces, lift and centrifugal force.

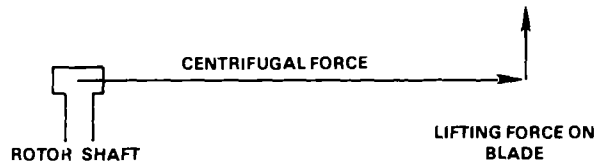


FIGURE 2-32. LIFT AND CENTRIFUGAL FORCE.

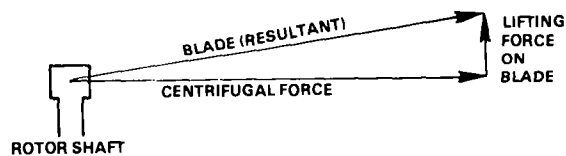


FIGURE 2-33. RESULTANT OF LIFT AND CENTRIFUGAL FORCES.

ROTATIONAL VELOCITIES

During hovering, airflow over the rotor blades is produced by rotation of the rotor system. Figure 2-34 shows a typical helicopter rotor system. An arbitrary rotor diameter of 40 feet and rotor speed of 320 revolutions per minute is used to illustrate typical rotational velocities. Blade tip velocity for this rotor is 670 feet per second which converts to 397 knots.

Blade speed near the main rotor shaft is much less because the distance traveled at the smaller radius is relatively small. At

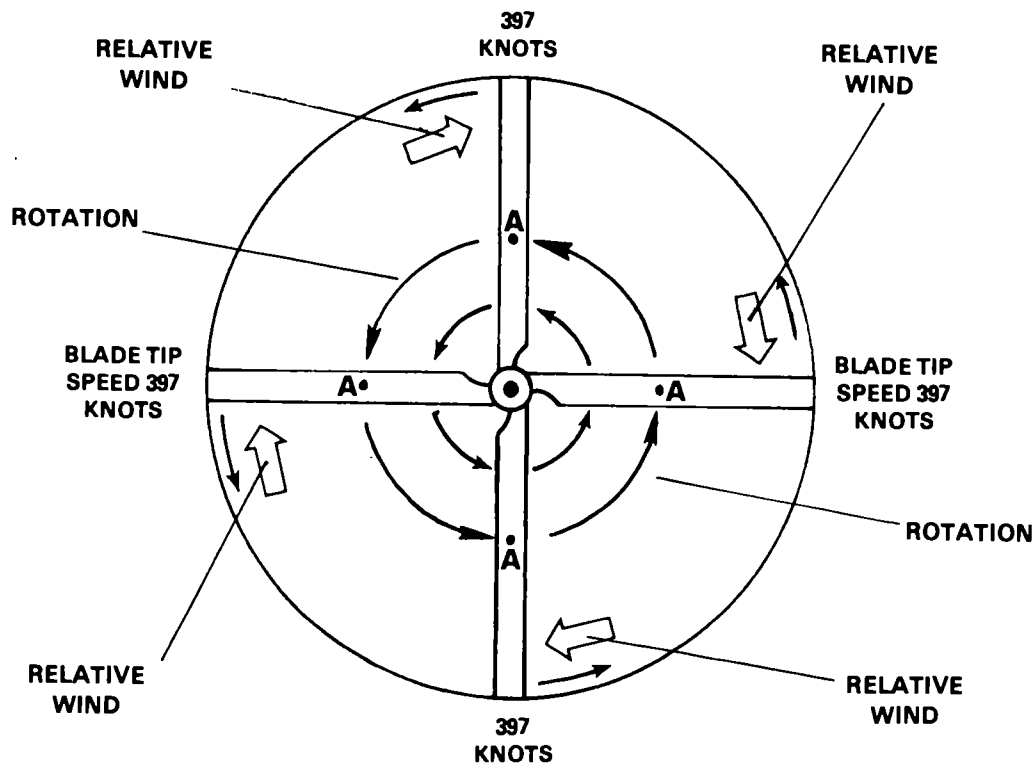


FIGURE 2-34. BLADE SPEED AT HOVER.

point A, figure 2-34, half way from the rotor shaft to the blade tip, the blade speed is only 198.5 knots which is one-half the tip speed. Speed at any point on the blades varies with the radius or distance from the center of the main rotor shaft. An extreme airspeed differential between the blade tip and root is the result. The lift differential between the blade root and tip is even larger because lift varies as the square of the speed. Therefore, when speed is doubled, lift is increased four times. This means that the lift at point A, figure 2-34, would be only one-fourth as much as lift at the blade tip (assuming the airfoil shape and angle of attack are the same at both points).

Because of the potential lift differential along the blade resulting primarily from speed variation, blades are designed with a twist. Blade twist provides a higher pitch angle at the root where speed is low and lower pitch angles nearer the tip where speed is higher. This design helps distribute the lift more evenly along the blade. It increases both the induced air velocity and the blade loading near the inboard section of the blade. Figure 2-35 compares the lift of a twisted and untwisted blade. Note that the twisted blade generates more lift near the root and less lift at the tip than the untwisted blade.

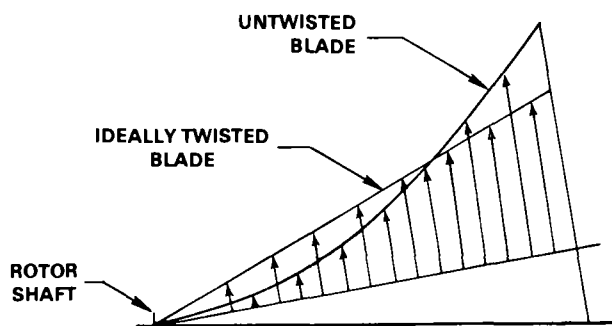


FIGURE 2-35. DISTRIBUTION OF LIFT ON TWISTED AND UNTWISTED BLADE.

HOVERING

Hovering is the term applied when a helicopter maintains a constant position at a selected point, usually a few feet above the ground. For a helicopter to hover, the main rotor must supply lift equal to the total weight of the helicopter. With the blades rotating at high velocity, an increase of blade pitch (angle of attack) would induce the necessary lift for a hover. The forces of lift and weight reach a state of balance during the stationary hover.

Hovering is actually an element of vertical flight. Assuming a no-wind condition, the tip-path plane of the blades will remain horizontal. If the angle of attack of the blades is increased while their velocity remains constant, additional vertical thrust is obtained. Thus, by upsetting the vertical balance of forces, the helicopter will climb vertically. By the same principle, the reverse is true; decreased pitch will result in the helicopter descending.

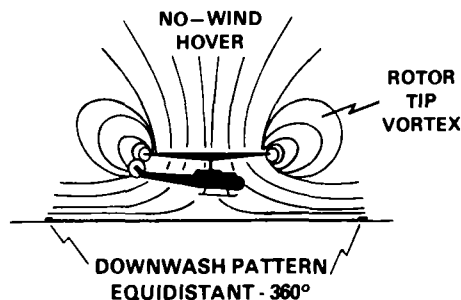


FIGURE 2-36. ROTOR TIP VORTEX AT A HOVER.

AIRFLOW DURING HOVERING

At a hover, the rotor tip vortex (air swirl at the tip of the rotor blades) reduces the effectiveness of the outer blade portions. Also, the vortices of the preceding blade severely affect the lift of the following blades. If the vortex made by one passing blade remains a vicious swirl for some number of seconds, then two blades operating at 350 RPM create 700 long-lasting vortex patterns per minute. This continuous creation of new vortices and ingestion of existing vortices is the primary cause of high power requirements for hovering (fig 2-36).

During hover, the rotor blades move large volumes of air in a downward direction. This pumping process uses lots of horsepower and accelerates the air to relatively high velocities. Air velocity under the helicopter may reach 60 to 100 knots, depending on the size and gross weight. The flow pattern and an airfoil

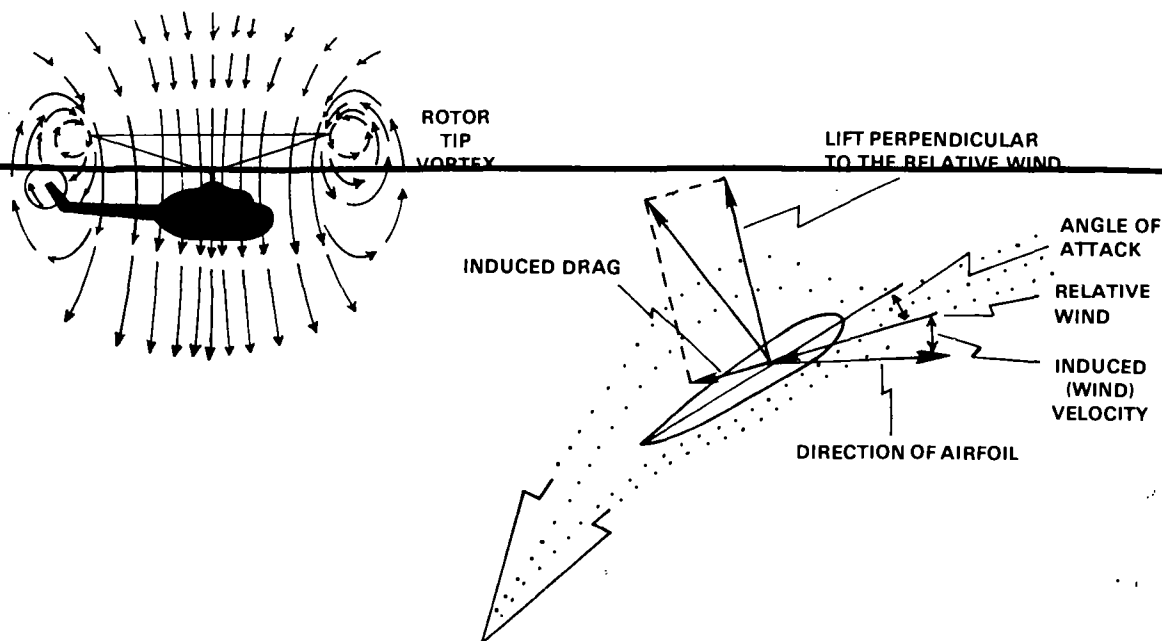


FIGURE 2-37. OUT-OF-GROUND-EFFECT HOVER.

section for a helicopter hovering out-of-ground-effect are shown in figure 2-37. Note how the downwash (induced flow) of air has introduced another element into the relative wind which alters the angle of attack of the airfoil. When there is no induced flow, the relative wind is opposite and parallel to the flightpath of the airfoil. In this case, the downward airflow (induced wind velocity) alters the relative wind and changes the angle of attack so less aerodynamic force is produced. This condition requires the pilot to increase collective pitch to produce enough aerodynamic force to sustain a hover.

GROUND EFFECT

The high power requirement needed to hover out-of-ground-effect (fig 2-37) is reduced when operating in ground effect

(fig 2-38). Ground effect is a condition of improved performance encountered when operating near the ground. It is due to interference of the surface with the airflow pattern of the rotor system; and it is more pronounced the nearer the ground is approached. Increased blade efficiency while operating in ground effect is due to two separate and distinct phenomena as follows:

□ First, and most important, is the reduction of the velocity of the induced airflow. Since the ground interrupts the airflow under the helicopter, the entire flow is altered. This reduces downward velocity of the induced flow. The result is less induced drag and a more vertical lift vector. The lift needed to sustain a hover can be produced with a reduced angle of attack and less power because of the more vertical lift vector (fig 2-38).

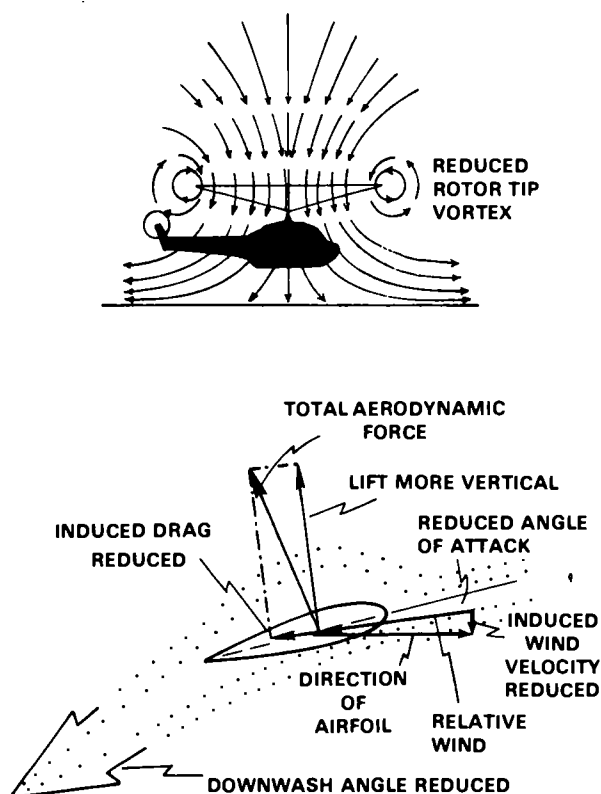


FIGURE 2-38. IN-GROUND-EFFECT HOVER.

□ The second phenomena is a reduction of the rotor *tip vortex* (fig 2-38). When operating in-ground-effect, the downward and outward airflow pattern tends to restrict vortex generation. This makes the outboard portion of the rotor blade more efficient and reduces overall system turbulence caused by ingestion and recirculation of the vortex swirls.

Rotor efficiency is increased by ground effect up to a height of about one rotor diameter for most helicopters. Figure 2-39 illustrates the percent increase in rotor thrust experienced at various rotor heights. At a rotor height of one-half rotor diameter, the thrust is increased about 7 percent.

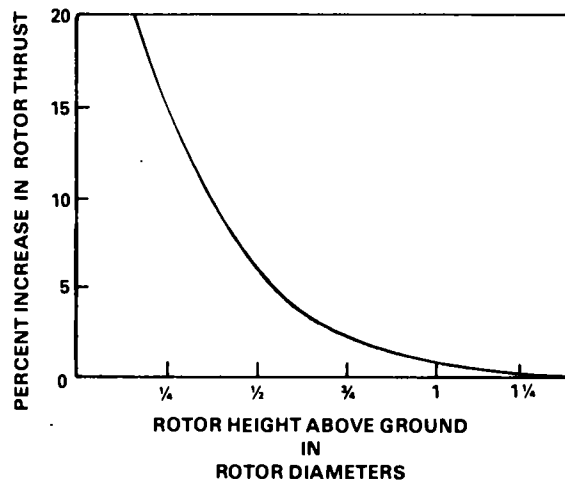


FIGURE 2-39. INCREASED LIFT CAPABILITY IN-GROUND-EFFECT.

At rotor heights above one rotor diameter, the thrust increase is small and decreases to zero at a height of about 1 1/4 rotor diameter.

Maximum ground effect is accomplished when hovering over smooth paved surfaces. While hovering over tall grass, rough terrain, revetments, or water, ground effect may be seriously reduced. This phenomena is due to the partial breakdown and cancellation of ground effect and the return of large vortex patterns with increased downwash angles.

Two identical airfoils with equal blade pitch angles are compared in figure 2-40. The top airfoil is out-of-ground-effect while the bottom airfoil is in-ground-effect. The airfoil that is in-ground-effect is more efficient because it operates at a larger angle of attack and produces a more vertical lift vector. Its increased efficiency results from a smaller downward induced

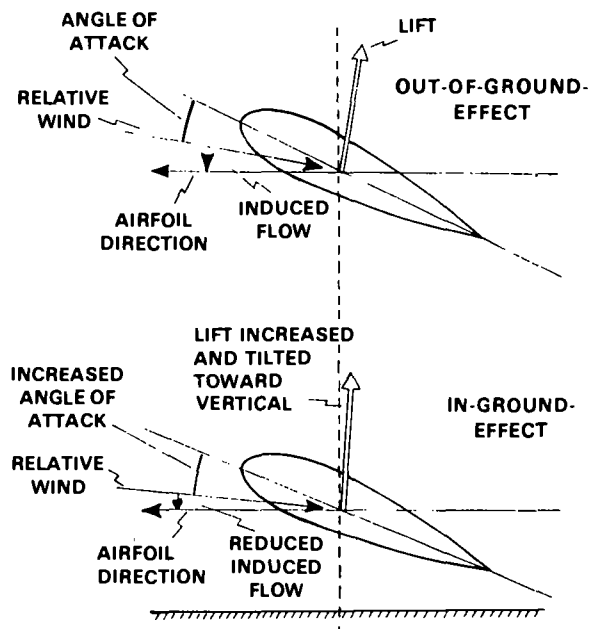


FIGURE 2-40. EFFECT OF GROUND PROXIMITY AT A CONSTANT PITCH ANGLE.

wind velocity which increases angle of attack. The airfoil operating out-of-ground-effect is less efficient because of increased induced wind velocity which reduces angle of attack.

If a helicopter hovering out-of-ground-effect descends into a ground-effect hover, blade efficiency increases because of the more favorable induced flow. As efficiency of the rotor system increases, the pilot reduces blade pitch angle to remain in the ground-effect hover. Less power is required to maintain hover in-ground-effect than for the out-of-ground-effect hover.

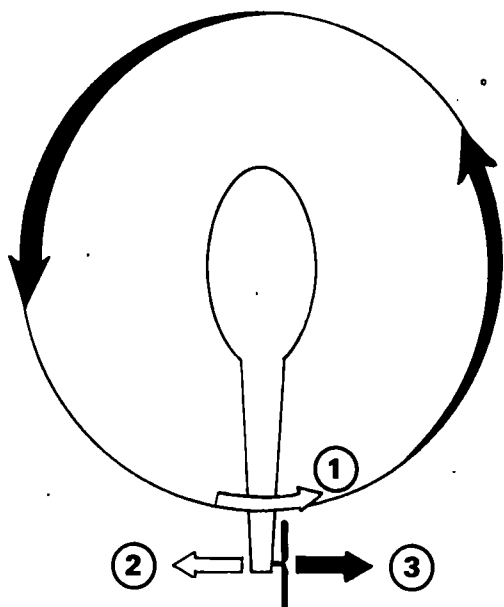
TORQUE

In accordance with Newton's law of action and reaction, the helicopter fuselage tends to rotate in the direction opposite to the rotor blades. This effect is called torque (②, figure 2-41). Torque must be counter-

acted and/or controlled before flight is possible. In tandem rotor and coaxial helicopter designs, the rotors turn in opposite directions to neutralize or eliminate torque effect. In tip-jet helicopters, power originates at the blade tip and equal and opposite reaction is against the air; there is no torque between the rotor and the fuselage. However, the torque problem is especially important in single main rotor helicopters with a fuselage-mounted power source. The torque effect on the fuselage (②, fig 2-41) is a direct result of the work/resistance of the main rotor. Therefore torque is at the geometric center of the main rotor. Torque results from the rotor being driven by the engine power output. Any change in engine power output brings about a corresponding change in torque effect. Furthermore, power varies with the flight maneuver and results in a variable torque effect that must be continually corrected.

ANTITORQUE ROTOR

Compensation for torque in the single main rotor helicopter is accomplished by means of a variable-pitch, antitorque rotor (tail rotor), located on the end of a tail boom extension at the rear of the fuselage. Driven by the main rotor at a constant ratio, the tail rotor produces thrust in a horizontal plane opposite to torque reaction developed by the main rotor (③, fig 2-41). Since torque effect varies during flight when power changes are made, it is necessary to vary the thrust of the tail rotor. Antitorque pedals enable the aviator to compensate for torque variance. A significant part of the engine power is required to drive the tail rotor, especially during operations where maximum power is used. From 5 to 15 percent of the available engine power may be needed to



1. Rotation direction of engine-driven main rotor.
2. Torque effect rotates fuselage in direction opposite to main rotor.
3. Tail rotor counteracts torque effect and provides positive fuselage heading control.

FIGURE 2-41. COMPENSATING TORQUE REACTION.

drive the tail rotor depending on helicopter size and design. Normally, larger helicopters use a higher percent of engine power to counteract torque than do smaller aircraft. A helicopter with 9,500 horsepower might require 1,200 horsepower to drive the tail rotor, while a 200 horsepower aircraft might require only 10 horsepower for torque correction.

HEADING CONTROL

In addition to counteracting torque, the tail rotor and its control linkage also permit control of the helicopter heading during taxiing, hovering, and sideslip operations on takeoffs and approaches. Application of

more control than is necessary to counteract torque will cause the nose of the helicopter to swing in the direction of pedal movement (left pedal to the left). Conversely, less pedal than required to counteract torque would permit the helicopter to turn in the direction of torque (i.e., nose would swing to the right). To maintain a constant heading at a hover or during takeoff or approach, an aviator must use antitorque pedals to apply just enough pitch on the tail rotor to neutralize torque and hold a slip if necessary. Heading control in forward trimmed flight is normally accomplished with cyclic control, using a coordinated bank and turn to the desired heading. Application of antitorque pedals will be required when power changes are made.

NOTE: In an autorotation, some degree of right pedal is required to maintain correct pedal trim. When torque is not present, as in an autorotation, mast thrust bearing friction tends to turn the fuselage in the same direction as (or with) the main rotor. To counteract this friction, the tail rotor thrust is at times reversed by the pilot and applied in a direction opposite to that required for torque correction in powered flight.

TRANSLATING TENDENCY

During hovering flight, the single rotor helicopter has a tendency to drift laterally to the right. The tendency results from right lateral tail rotor thrust that is exerted to compensate for main rotor torque (fig 2-42). The pilot may prevent right lateral drift of the helicopter by tilting the main rotor disk to the left. This lateral tilt results in a main rotor force to the left that

compensates for the tail rotor thrust to the right.

Helicopter design usually includes one or more features which help the pilot compensate for translating tendency.

□ Flight control rigging may be designed so the rotor disk is tilted slightly left when the cyclic control is centered.

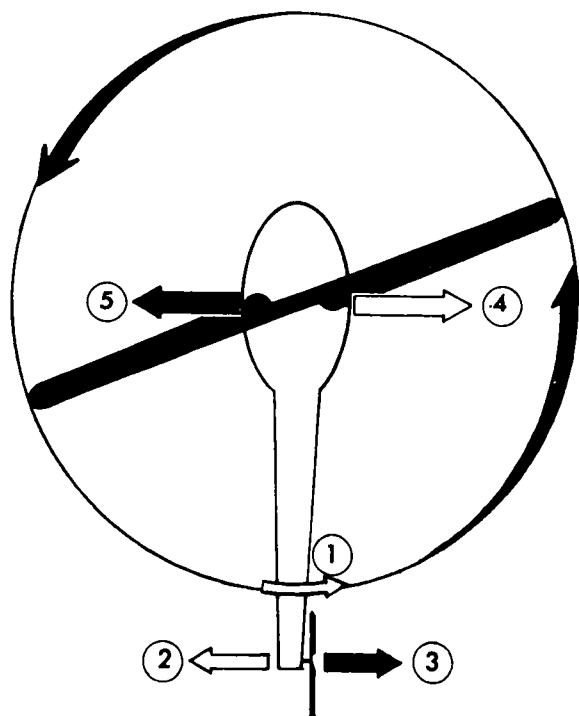
□ The main transmission may be mounted so that the mast is tilted slightly to the left when the helicopter fuselage is laterally level.

□ The collective pitch control system may be designed so that the rotor disk tilts slightly left, as collective pitch is increased to hover aircraft.

FUSELAGE HOVERING ATTITUDE

The design of most fully articulated rotor systems includes an offset between the main rotor mast and the blade attachment point. Centrifugal force acting on the offset tends to hold the mast perpendicular to the tip-path plane (A, fig 2-43). As a result, when the rotor disk is tilted left to counteract translating tendency, the fuselage will follow the main rotor mast and hang slightly low on the left side (B, fig 2-43).

A fuselage suspended under a semirigid rotor system will remain level laterally unless the load is unbalanced or the tail rotor gearbox is lower than the main rotor (B, fig 2-45). The fuselage remains level because there is no offset between the rotor mast and the point where the rotor system is attached to the mast (trunnion bearings).



- 1 Rotation direction of engine-driven main rotor.
- 2 Torque effect rotates fuselage in direction opposite to main rotor.
- 3 Tail rotor counteracts torque effect and provides positive fuselage heading control.
- 4 Tail rotor pulls or pushes entire helicopter into right drift (translating tendency).
- 5 As necessary to prevent right drift, pilot applies left rotor tilt to counteract translating tendency.

FIGURE 2-42. COMPENSATING FOR TRANSLATING TENDENCY.

Because the trunnion bearings are centered on the mast, the mast has no tendency to follow the tilt of the rotor disk during hovering (fig 2-44). The mast does not tend to remain perpendicular to the tip-path plane as is true with the fully articulated rotor system. Instead, the mast tends to hang vertically under the trunnion bearings even when the rotor disk is tilted left to compensate for translating tendency (A, fig 2-45). Because the mast remains vertical, the fuselage hangs level laterally unless it is affected by other forces.

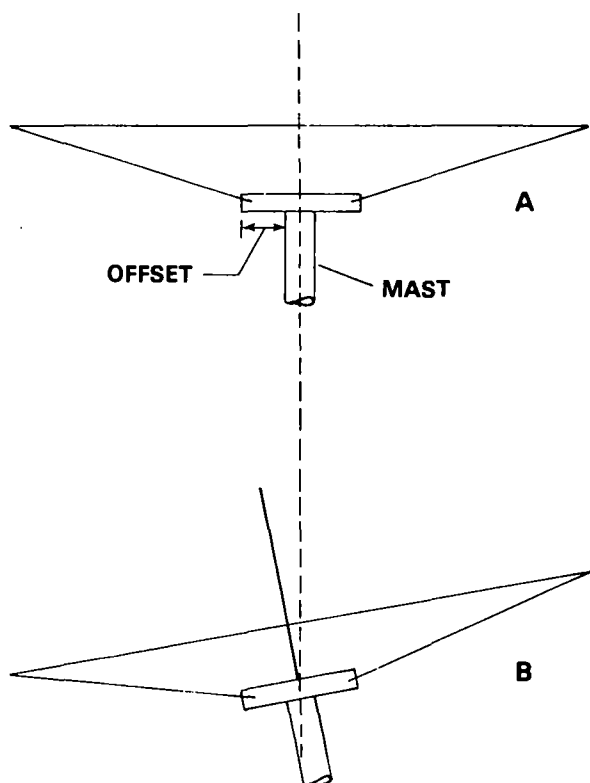


FIGURE 2-43. FULLY ARTICULATED ROTOR SYSTEM.

The main rotor mast in semirigid and fully articulated rotor systems may be designed with a forward tilt relative to the fuselage. Forward tilt provides for a level longitudinal fuselage attitude during forward flight (resulting in reduced parasite drag), but results in a tail low fuselage attitude during hovering. When the fuselage is tail low, the tail rotor gearbox will be lower than the main rotor. During hover, this causes a slightly unbalanced couple between the tail rotor and the main rotor which makes the fuselage tilt laterally to the left (B, fig 2-45).

AIRFLOW IN FORWARD FLIGHT

The efficiency of the hovering rotor system is improved with each knot of

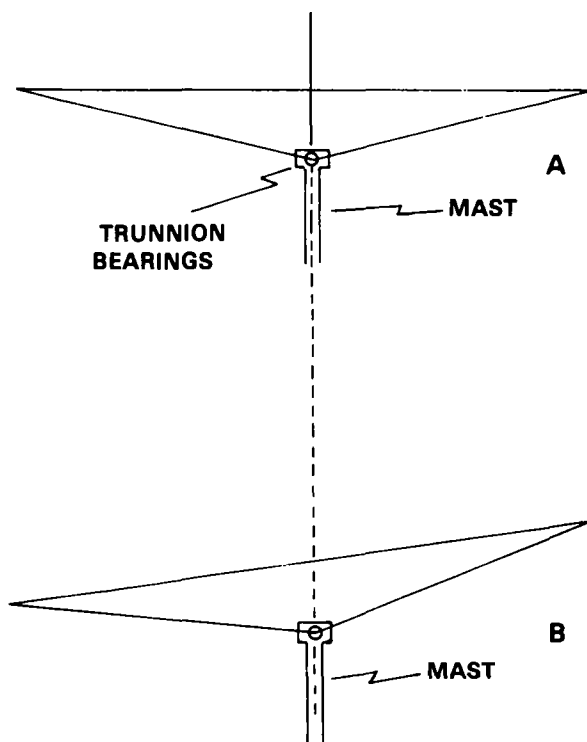


FIGURE 2-44. SEMIRIGID ROTOR SYSTEM.

incoming wind gained by horizontal movement or surface wind. As the incoming wind enters the rotor system, turbulence and vortices are left behind and the flow of air becomes more horizontal. All of these changes improve the efficiency of the rotor system and improve aircraft performance.

Improved rotor efficiency resulting from directional flight is called *translational lift*. An airflow pattern for a forward speed of 1 to 5 knots is shown in figure 2-46. Note how the downwind vortex is beginning to dissipate and induced flow down through the rear of the rotor disk is more horizontal than at a hover (fig 2-38).

Figure 2-47 shows the airflow pattern at a speed of 10 to 15 knots. Airflow is much

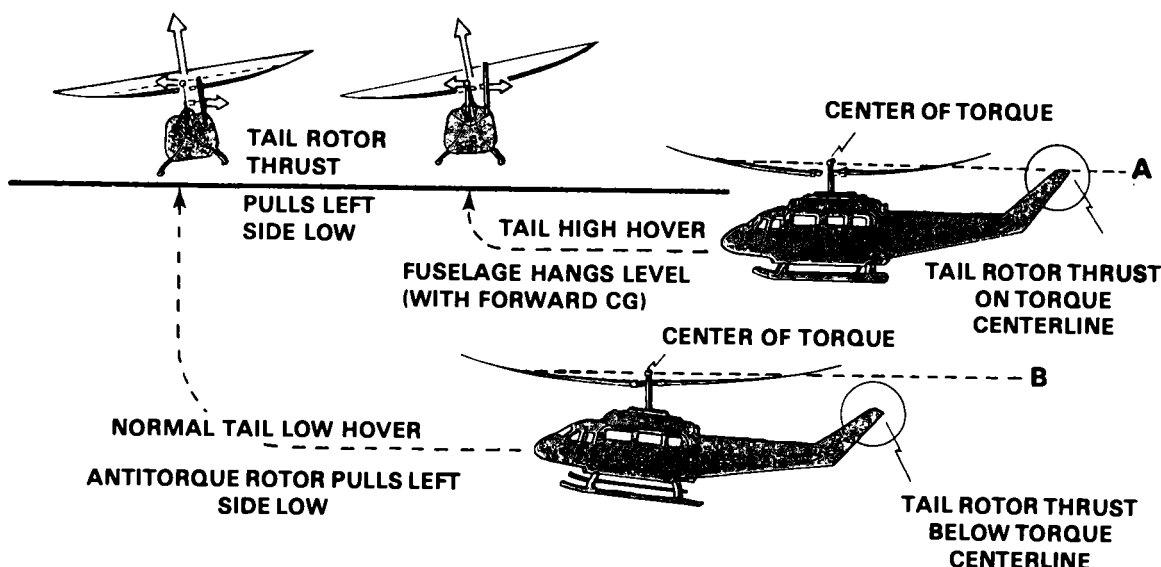


FIGURE 2-45. EFFECT OF TAIL LOW ATTITUDE ON LATERAL HOVER ATTITUDE.

more horizontal than at a hover. The leading edge of the downwash pattern is being overrun and is well back under the helicopter nose. At about 16 to 24 knots (depending upon the size, blade area, and RPM of the rotor system) the rotor completely outruns the recirculation of old vortices and begins to work in relatively clean air. The rotor no longer pumps the air in a circular pattern, but continually flies into undisturbed air. The air passing through the rotor system is nearly horizontal, depending on helicopter forward speed.

As the helicopter speed increases, translational lift becomes more effective and causes the nose to rise, or pitch up (sometimes called blowback). This tendency is caused by the combined effects of dissymmetry of lift and transverse flow which are explained in detail in later paragraphs. Pilots must correct for this

tendency in order to maintain a constant rotor disk attitude that will move the helicopter through the speed range where blowback occurs. If the nose is permitted to pitch up while passing through this speed range, the aircraft may also tend to roll slightly to the right.

When the single main rotor helicopter transitions from hover to forward flight, the tail rotor becomes more aerodynamically efficient. Efficiency increases because the tail rotor works in progressively less turbulent air as speed increases. As tail rotor efficiency improves, more thrust is produced. This causes the aircraft nose to yaw left if the main rotor turns counter-clockwise. During a takeoff where power is constant, the pilot must apply right pedal as speed increases to correct for the left yaw tendency.

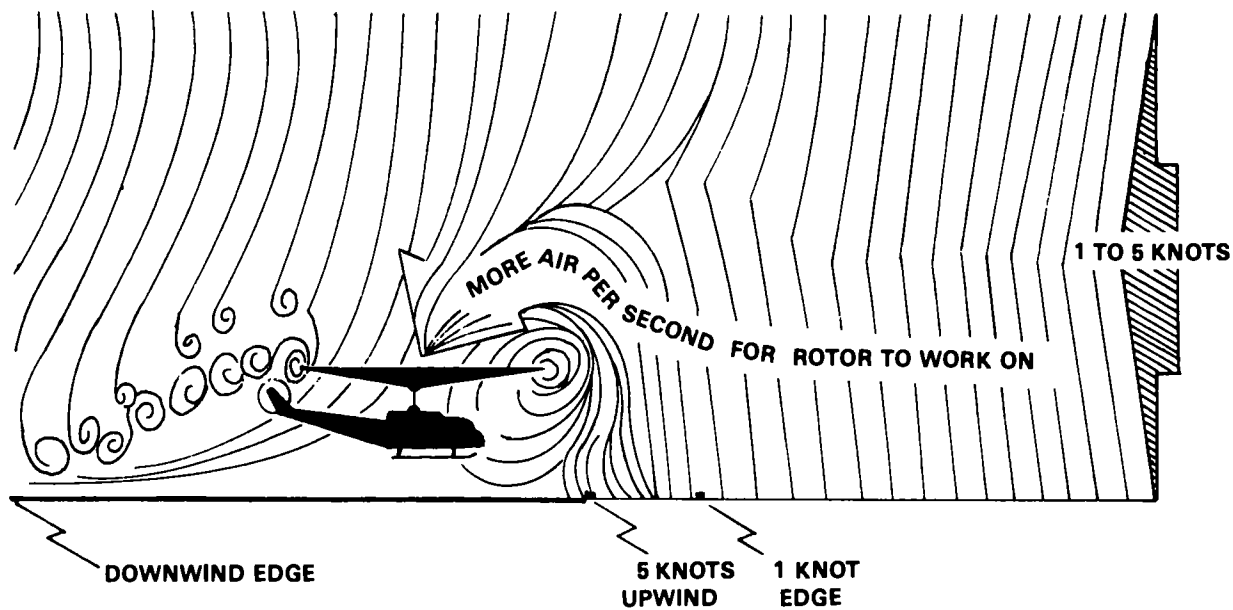


FIGURE 2-46. TRANSLATIONAL LIFT AT 1 to 5 KNOTS.

AIRFLOW PATTERN JUST PRIOR TO
EFFECTIVE TRANSLATIONAL LIFT

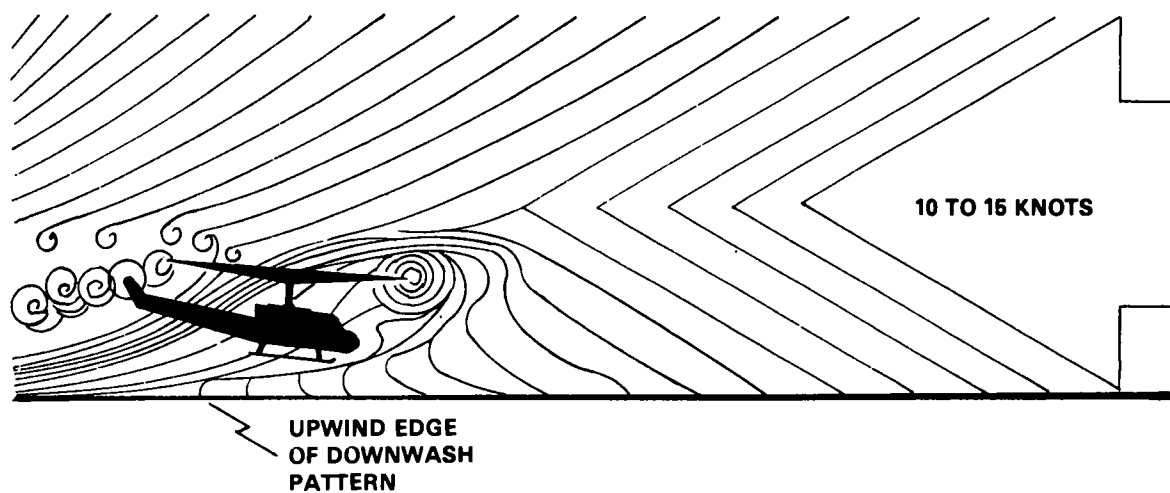


FIGURE 2-47. TRANSLATIONAL LIFT AT 10 TO 15 KNOTS.

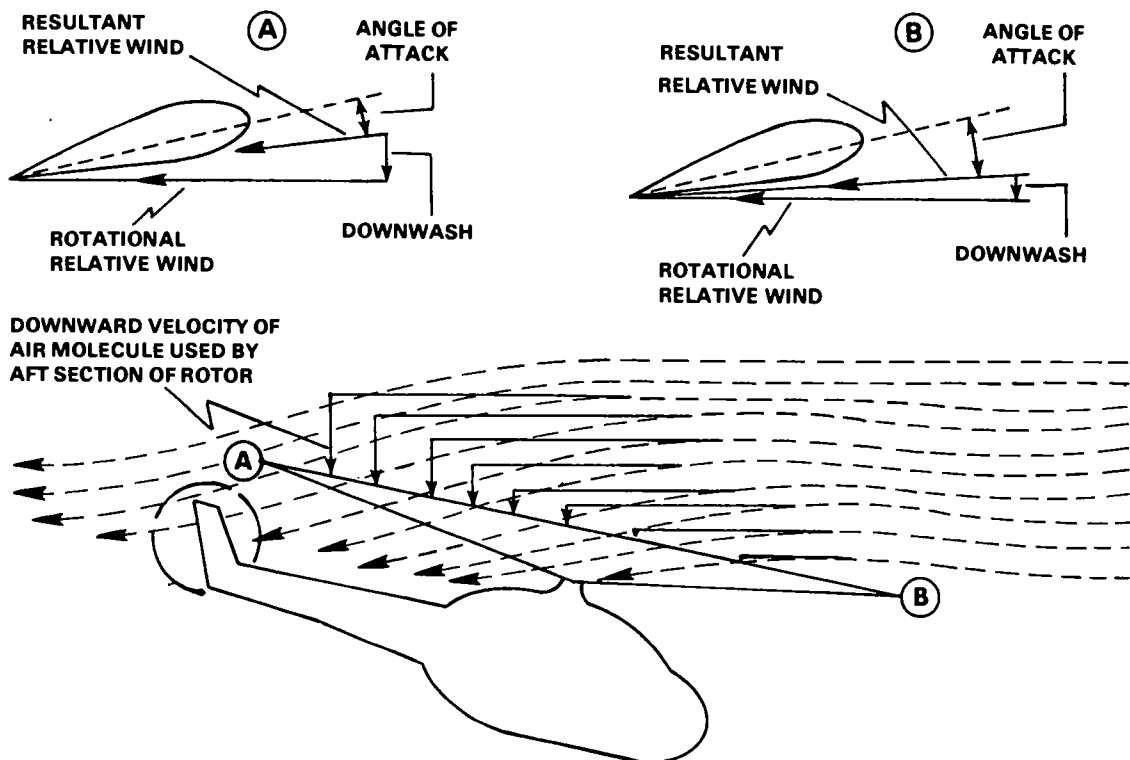


FIGURE 2-48. TRANSVERSE FLOW EFFECT.

TRANSVERSE FLOW EFFECT

In forward flight, air passing through the rear portion of the rotor disk has a greater downwash angle than air passing through the forward portion (fig 2-48). The downward flow at the rear of the rotor disk causes a reduced angle of attack, resulting in less lift. Increased angle of attack, and more lift is produced at the front portion of the disk because airflow is more horizontal. These differences between the fore and aft parts of the rotor disk are called transverse flow effect. They cause unequal drag in the fore and aft parts of the disk resulting in vibrations that are easily recognizable by the pilot. The vibrations are more noticeable for most helicopters between 10 and 20 knots.

DISSYMMETRY OF LIFT

Dissymmetry of lift is the difference in lift that exists between the advancing half of the rotor disk and the retreating half. It is caused by the fact that in directional flight the aircraft relative wind is added to the rotational relative wind on the advancing blade and subtracted on the retreating blade (fig 2-49). The blade passing the tail and advancing around the right side of the helicopter has an increasing airspeed which reaches maximum at the 3 o'clock position. As the blade continues, the airspeed reduces to essentially rotational airspeed over the nose of the helicopter. Leaving the nose, the blade airspeed progressively decreases and reaches minimum airspeed at

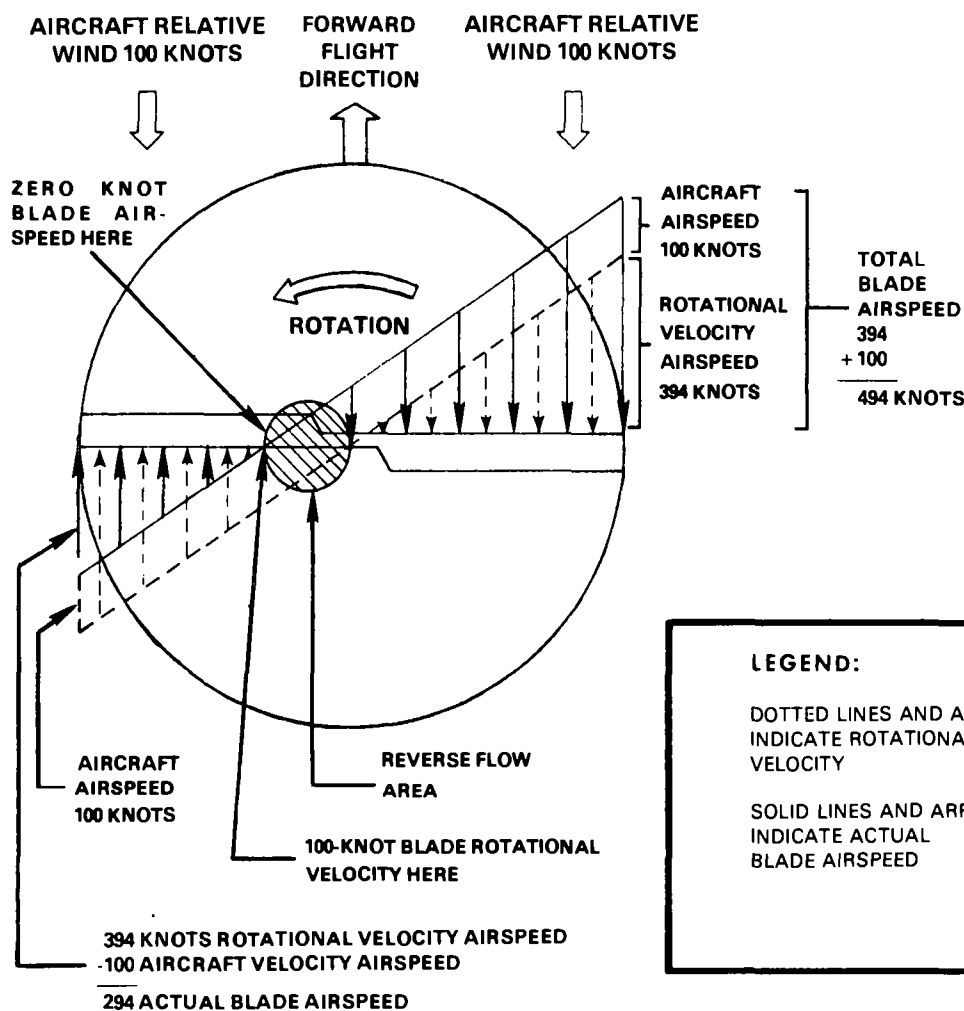


FIGURE 2-49. DISSYMMETRY OF LIFT.

the 9 o'clock position. The blade airspeed then increases progressively and again reaches rotational airspeed as it passes over the tail.

Note the shaded circle in figure 2-49 labeled "REVERSE FLOW AREA." Blade airspeed at the outboard edge of the shaded circle is 0 knots. Within the reverse flow area, the air actually moves over the blade backwards from trailing edge to

leading edge. From the reverse flow area out to the blade tip, the blade airspeed progressively increases up to 294 knots.

At an aircraft airspeed of 100 knots (fig 2-49), a 200-knot blade airspeed differential exists between the advancing and retreating blades. Since lift increases as the square of the airspeed, a potential lift variation exists between the advancing and retreating sides of the rotor disk. This lift

differential must be compensated for, or the helicopter would not be controllable.

To compare the lift of the advancing half of the disk area to the lift of the retreating half, the lift equation discussed earlier can be used. In forward flight, two factors in the lift formula, density ratio (ρ) and blade area (S), are the same for both the advancing and retreating blades. The airfoil shape (one part of C_L) is fixed for a given blade. The only remaining variables are changes in blade angle of attack (another part of C_L) and blade airspeed. These two variables must compensate for each other during forward flight to overcome dissymmetry of lift.

Two factors, *rotor RPM* and *aircraft airspeed*, control blade airspeed during flight. Both factors are variable to some degree, but must remain within certain operating limits specified for the aircraft. Angle of attack remains as the one variable that may be used by the pilot to compensate for dissymmetry of lift. The pitch angle of the rotor blades can be varied throughout their range, from flat pitch to the stalling pitch angle, to change angle of attack and to compensate for lift differential.

Figure 2-50 illustrates the relationship between blade pitch angle and blade airspeed during forward flight. Note that blade pitch angle is lower on the advancing side of the disk to compensate for increased blade airspeed on that side. Blade pitch

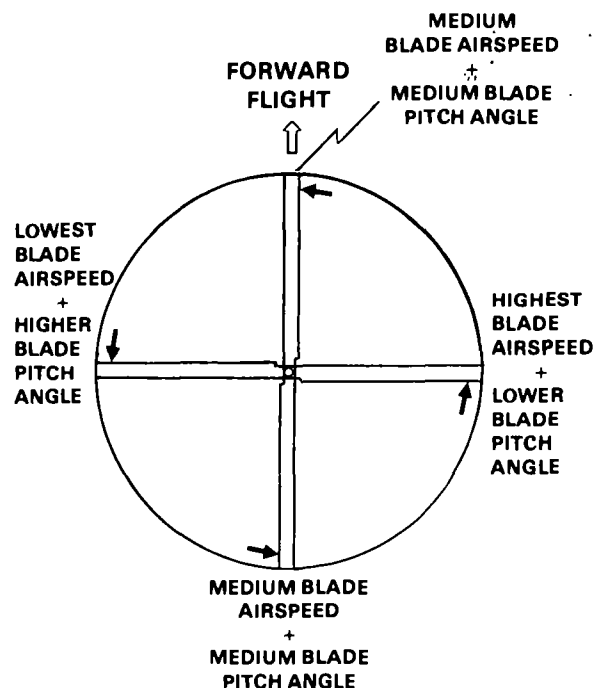


FIGURE 2-50. BLADE PITCH ANGLE VARIATION TO COMPENSATE FOR DISSYMMETRY OF LIFT.

angle is increased on the retreating blade side to compensate for decreased blade airspeed on that side. These changes in blade pitch are introduced through the blade feathering mechanism and are called cyclic feathering. Pitch changes are made to individual blades independent of the others in the system and are controlled by the pilot's cyclic pitch stick.

The tail rotor experiences dissymmetry of lift during forward flight, because it has advancing and retreating blades. Dissymmetry is corrected for by a flapping hinge action. Two basic types of flapping hinges, the *delta* hinge and the *offset* hinge, are used on most contemporary helicopters.

(a) Plain flapping hinge. (b) Delta-three hinge combines flapping and cyclic feathering.

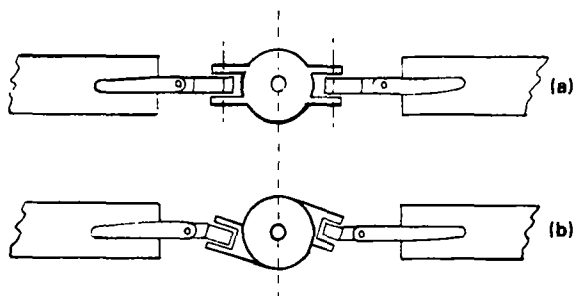


FIGURE 2-51. FLAPPING HINGES.

Flapping hinge offset from center produces moments without disk tilt.

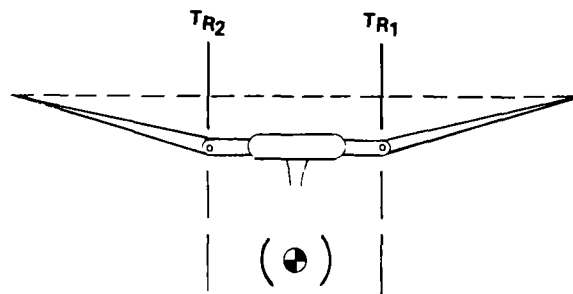


FIGURE 2-52. OFFSET FLAPPING HINGE.

The delta hinge is not oriented parallel to the blade chord (fig 2-51). It is designed so flapping automatically introduces cyclic feathering which corrects for dissymmetry of lift. The offset hinge is located outboard from the hub (fig 2-52). The offset hinge uses centrifugal force to produce substantial forces that act on the hub. One important advantage of offset hinges is the presence of control regardless of lift condition, since centrifugal force is independent of lift.

BLADE FLAPPING

Blade flapping is the up and down movement of a rotor blade, and is the primary way of compensating for lift dissymmetry. Flapping action varies, depending on the type rotor system. In the fully articulated rotor system, blades flap individually about a horizontal hinge pin. Each blade is free to move up and down independently from all the other blades.

Semirigid rotor systems flap somewhat differently than fully articulated systems. A blade in a semirigid system is not free to flap independently of the other blade. Instead, if one blade flaps up, the other must flap down, since they move together on a common teetering hinge. Some independent flapping can take place through blade flexing.

Rigid rotor systems have no hinge to permit flapping to take place. They depend entirely on structural bending or flexing to perform the flapping action.

Flapping action corrects for dissymmetry of lift on the advancing side by changing the angle of attack as illustrated in B, figure 2-53. Blade angle of attack over the tail is shown in A, figure 2-53. As the blade moves forward from the tail on the advancing side, blade airspeed begins to increase and produces more lift. The blade responds by climbing (flapping up). Flapping up introduces a vertical vector into the

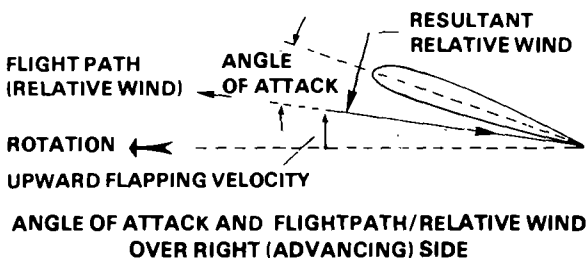
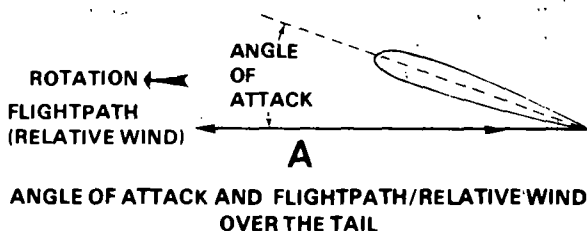


FIGURE 2-53. ANGLE OF ATTACK CHANGES CAUSED BY FLAPPING.

relative wind which effectively decreases the angle of attack (B, fig 2-53). The upward flapping velocity is just enough to reduce angle of attack, so lift is kept essentially constant.

Flapping action on the retreating side of the rotor disk works similarly, except flapping is down instead of up. Angle of attack as the blade passes over the aircraft nose is shown in A, figure 2-54. As the blade moves rearward from the nose on the retreating side, blade airspeed begins to decrease and produces less lift. The blade responds by descending (flapping down). Flapping down introduces a downward velocity into the relative wind which effectively increases the angle of attack,

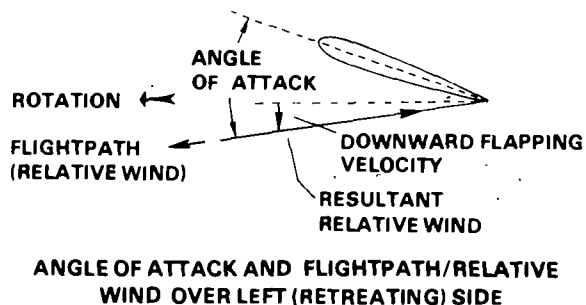
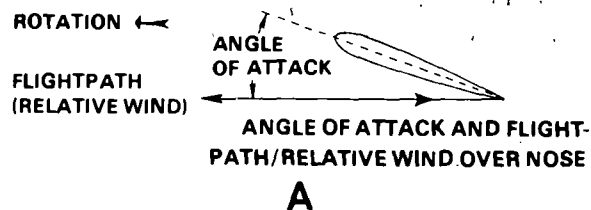


FIGURE 2-54. ANGLE OF ATTACK CHANGES CAUSED BY FLAPPING.

causing more lift to be produced (B, fig 2-54). Downflapping velocity is just enough to increase the angle of attack, so lift is kept constant.

GYROSCOPIC PRECESSION

Gyroscopic precession is a phenomenon occurring in rotating bodies in which an applied force is manifested 90° ahead in the direction of rotation from where the force was applied. Although precession is not a dominant force in rotary-wing aerodynamics, it must be reckoned with because turning rotor systems exhibit some of the

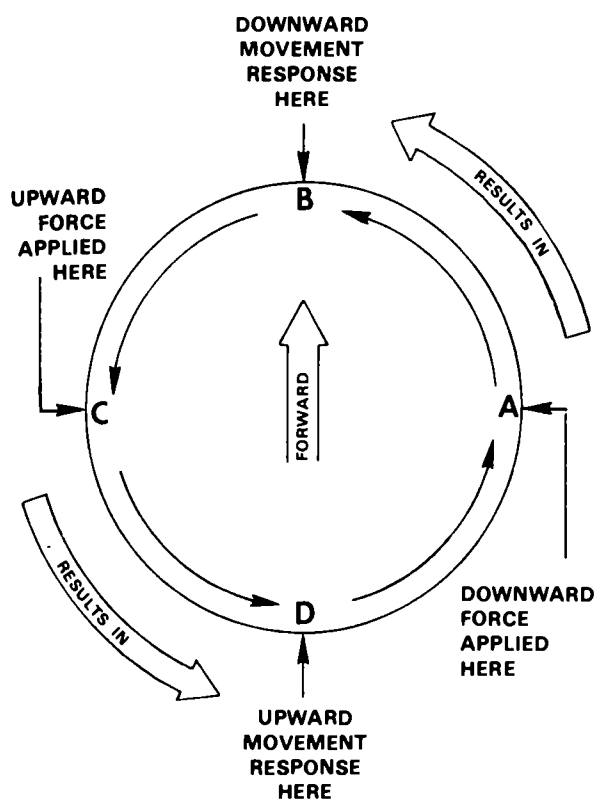


FIGURE 2-55. GYROSCOPIC PRECESSION.

characteristics of a gyro. Figure 2-55 shows how precession affects the rotor disk when force is applied at a given point. A downward force applied to the disk at point A results in a downward change in disk attitude at point B. An upward force applied at point C results in an upward change in disk attitude at point D.

Forces applied to a spinning rotor disk by control input or by wind gusts will react as follows:

<i>Force Causing</i>	
<i>Aircraft Movement</i>	<i>Aircraft Reaction</i>
nose up _____	roll right
nose down _____	roll left
roll right _____	nose up
roll left _____	nose down

This behavior explains some of the fundamental effects occurring during various helicopter maneuvers. For example, the helicopter behaves differently when rolling into a right turn than when rolling into a left turn. During roll into a left turn, the pilot will have to correct for a nose down tendency in order to maintain altitude. This correction is required because precession causes a nose down tendency and because the tilted disk produces less vertical lift to counteract gravity. Conversely, during a roll into a right turn, precession will cause a nose up tendency while the tilted disk will produce less vertical lift. Pilot input required to maintain altitude is significantly different during a right turn than during a left turn, because gyroscopic precession acts in opposite directions for each.

ROTOR HEAD CONTROL SYSTEMS

□ *Cyclic and Collective Pitch.* Pilot inputs to the cyclic and collective pitch

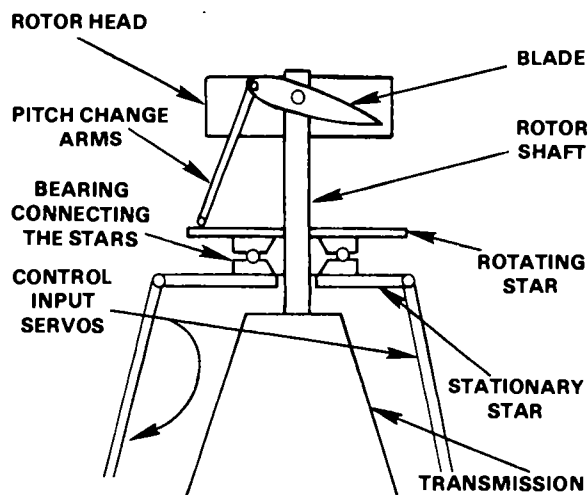


FIGURE 2-56. ROTOR HEAD CONTROL SYSTEM.

controls are transmitted to the rotor blades through a complex system of levers, mixing units, input servos, stationary and rotating stars (swashplates), and pitch change arms (fig 2-56). In its simplest form, movement of the collective pitch control causes the stationary and rotating stars, mounted centrally on the rotor shaft, to rise and descend. Movement of the cyclic pitch control causes the stars to tilt, the direction of tilt being controlled by the direction in which the cyclic stick is moved (fig 2-57).

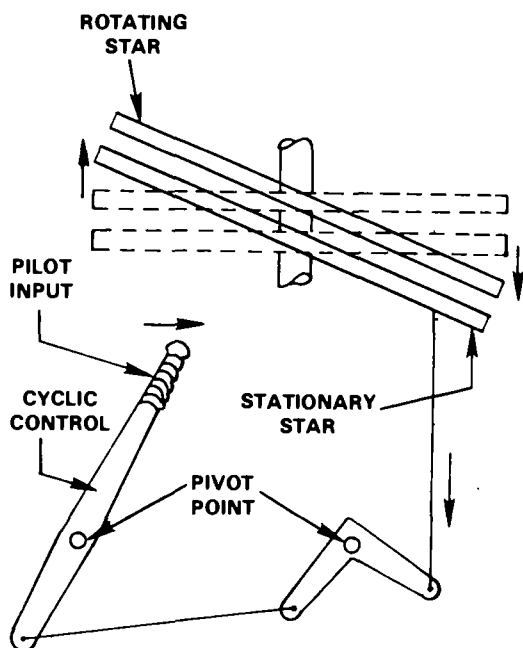


FIGURE 2-57. STATIONARY AND ROTATING STARS TILTED BY CYCLIC CONTROL.

Figure 2-58 illustrates a star that is tilted 2° . Notice the amount the star has been tilted at four positions, A, B, C and D. Points A and C form the axis about which the tilt occurs. At that axis the star remains at zero degrees. When the star is moved, the resulting motion change is

transmitted to the rotor blade through pitch change arms. As the pitch change arms move up and down with each rotation of the star, blade pitch is constantly

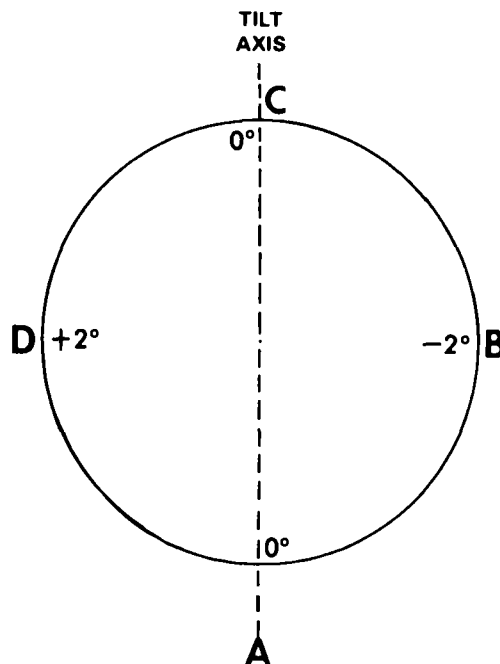
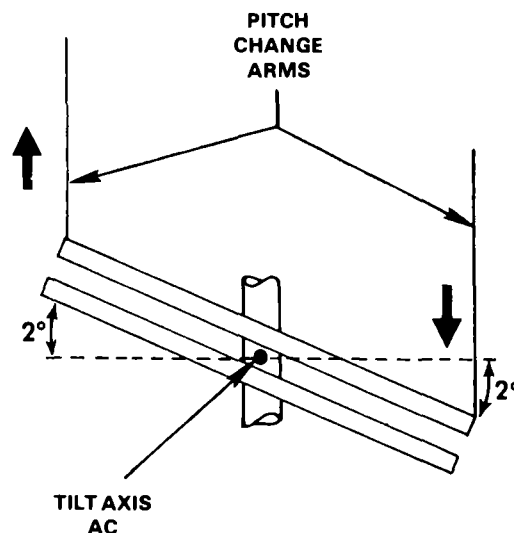


FIGURE 2-58. STATIONARY AND ROTATING STARS TILTED IN RELATION TO MAST.

increased or decreased. If cyclic control is applied to tilt the rotor, the addition of collective pitch does not change the tilt of the star and rotor. It simply moves the star upward, so pitch is increased an equal amount on all blades simultaneously.

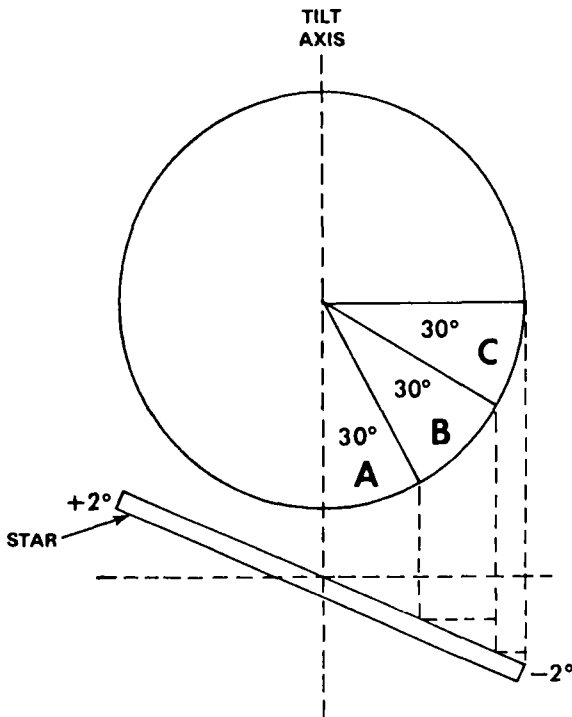


FIGURE 2-59. PITCH CHANGE ARM RATE OF MOVEMENT OVER 90° OF TRAVEL.

Figure 2-59 further illustrates how the pitch change arms move up and down on the tilted star. Rate of vertical change throughout the rotation is not uniform. Vertical movement is larger during the 30° of rotation at A than at B and C, respectively. This variation is repeated during each 90° of rotation. Rate of vertical movement is lowest at the low and high points of the star. Highest rates of vertical movement occur when the pitch change arms pass by the tilt axis of the star.

By means of cyclic pitch change, the rotor blades are caused to climb from point A to point B and then dive from point B to point A (fig 2-60). The rotor is tilted in the direction of desired flight in this way. In order for the blades to pass through points A and B, as shown in figure 2-60, it is obvious they must flap up and down on a hinge or teeter on a trunnion. When the blades are at the lowest flapping point (A, fig 2-60), it would appear that they would also be at their lowest pitch angle; and that at point B where they are at their highest flapping point, they would be at their highest pitch. If only aerodynamic considerations were involved this might be true. Because of phase lag, these points are separated by 90°.

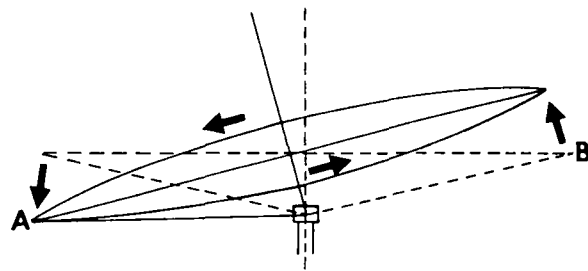


FIGURE 2-60. ROTOR FLAPPING IN RESPONSE TO CYCLIC INPUT.

□ *Phase Lag.* In fact, the points of highest and lowest flapping are located 90° in the direction of rotation from the points of highest and lowest blade pitch. This phenomenon is called *phase lag*. The rotor control system is designed to correct for it, so the pilot is able to tilt the rotor disk in any direction by simply moving the cyclic control in that same direction.

Figure 2-61 illustrates a typical design feature that offsets cyclic control input 90°

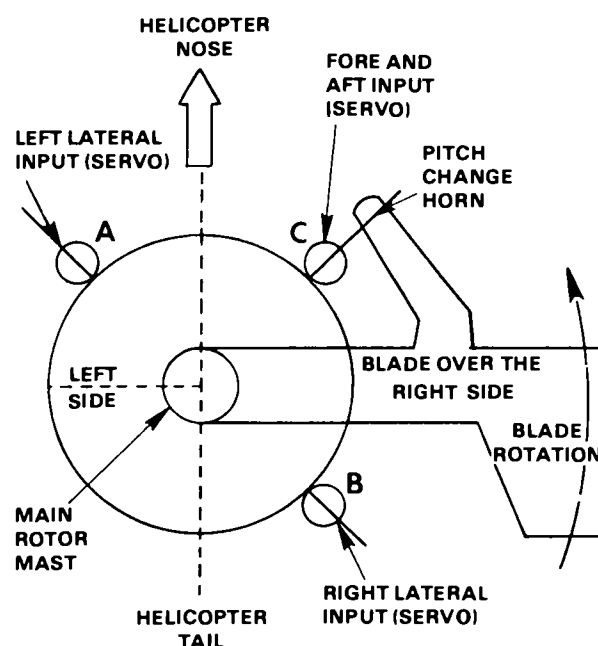


FIGURE 2-61. INPUT SERVO AND PITCH HORN OFFSET.

from where rotor tilt is desired. Rotor control input locations are the left lateral servo (A), right lateral servo (B), and the fore and aft servo (C). Note that each servo is offset 45° from the position corresponding to its name. For example, the fore and aft input servo is not located at the nose or tail position; instead, it is at the right front about halfway between the nose and the 3 o'clock position. Similarly, the left lateral servo is located halfway between the nose and the 9 o'clock position. The right lateral servo is stationed halfway between the tail and the 3 o'clock position. Location of the input servos accounts for part of the offset that is needed to correct for phase lag. Note also that the rotor blade has a pitch change horn that extends ahead of the blade in the plane of rotation about 45° . Pilot control inputs are transmitted from the input servos to the pitch change horn by a connecting rod called a pitch change rod.

Design of the pitch change horn, coupled with servo placement, provides the total offset necessary to compensate for phase lag.

Figure 2-62 illustrates typical cyclic pitch variation for a blade through one revolution with the cyclic pitch control full forward. Degree figures shown are for a typical aircraft rotor system and would vary depending on the type helicopter. Note that the input servos and pitch change horns are offset as described in the previous paragraph. With the cyclic pitch control in the full forward position, blade pitch angle is highest at the 9 o'clock position and lowest at the 3 o'clock position. Pitch angle begins decreasing as it passes 9 o'clock and decreases continually until it reaches the 3 o'clock position. As the blade moves forward from 3 o'clock, pitch begins to increase and reaches maximum pitch angle at 9 o'clock. Blade pitch angles over the nose and tail are about equal.

The blades reach a point of lowest flapping over the nose 90° in the direction of rotation from the point of lowest pitch angle (fig 2-62). Highest flapping occurs over the tail, 90° in the direction of rotation from the point of highest pitch angle. Simply stated, the force (pitch change) which causes blade flap must be applied to the blade 90° of rotation preceding the point where maximum blade flap is desired.

Patterns similar to figure 2-60 could be constructed for other cyclic positions in the circle of cyclic travel. In each case, the same principles apply. Points of highest and lowest flapping will be located 90° in the direction of rotation from the points of highest and lowest blade pitch.

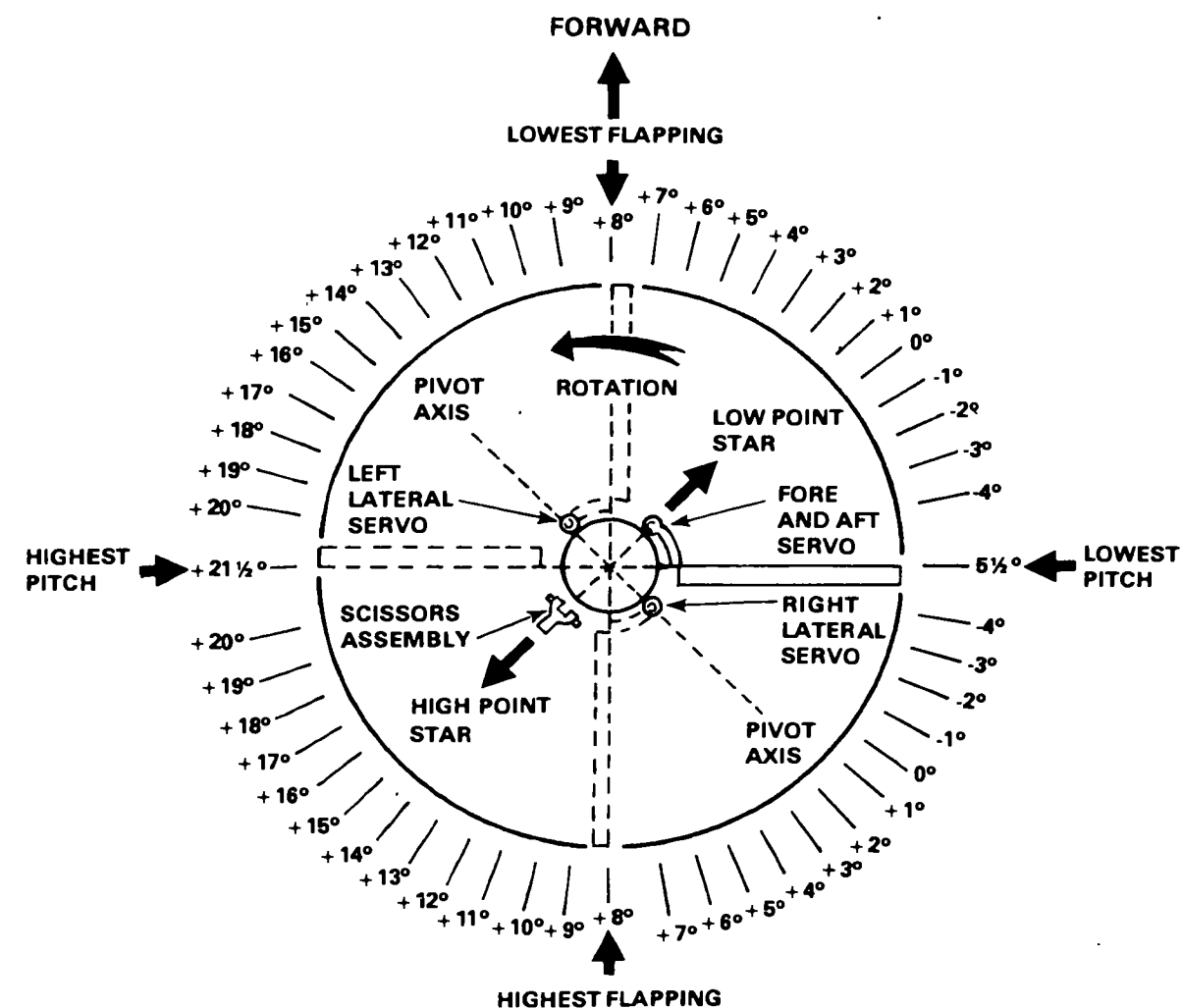


FIGURE 2-62. CYCLIC PITCH VARIATION—FULL FORWARD, LOW PITCH.

RETREATING BLADE STALL

□ **Stall Tendency.** A tendency for the retreating blade to stall in forward flight is inherent in all present-day helicopters, and is a major factor in limiting their forward speed. Just as the stall of an airplane wing limits the low speed possibilities of the airplane, the stall of a rotor blade limits the high speed potential of a helicopter (fig 2-63). The airspeed of the retreating blade (the blade moving away from the direction of flight) slows down as forward speed increases. The retreating blade must, however, produce an amount of lift equal to that of the advancing blade (B, fig 2-63). Therefore, as the airspeed of the retreating blade decreases with forward speed, the blade angle of attack must be increased to equalize lift throughout the rotor disk area. As this angle increase is continued, the blade will stall at some high forward speed (C, fig 2-63).

As forward airspeed increases, the "no lift" areas (fig 2-63) move left of center, covering more of the retreating blade sectors. This requires more lift at the outer retreating blade portions to compensate for the loss of lift of the inboard retreating sections. In the area of reversed flow, the rotational velocity of this blade section is slower than the aircraft airspeed; therefore, the air flows from the trailing to leading edge of the airfoil. In the negative stall area, the rotational velocity of the airfoil is faster than the aircraft airspeed; therefore, air flows from leading to trailing edge of the blade. However due to the relative arm and induced flow, blade flapping is not sufficient to produce a positive angle of attack. Blade flapping and rotational velocity in the negative lift area are sufficient to produce a positive angle of attack, but not to a degree that produces appreciable lift.

OPEN FOR
FOLDOUT

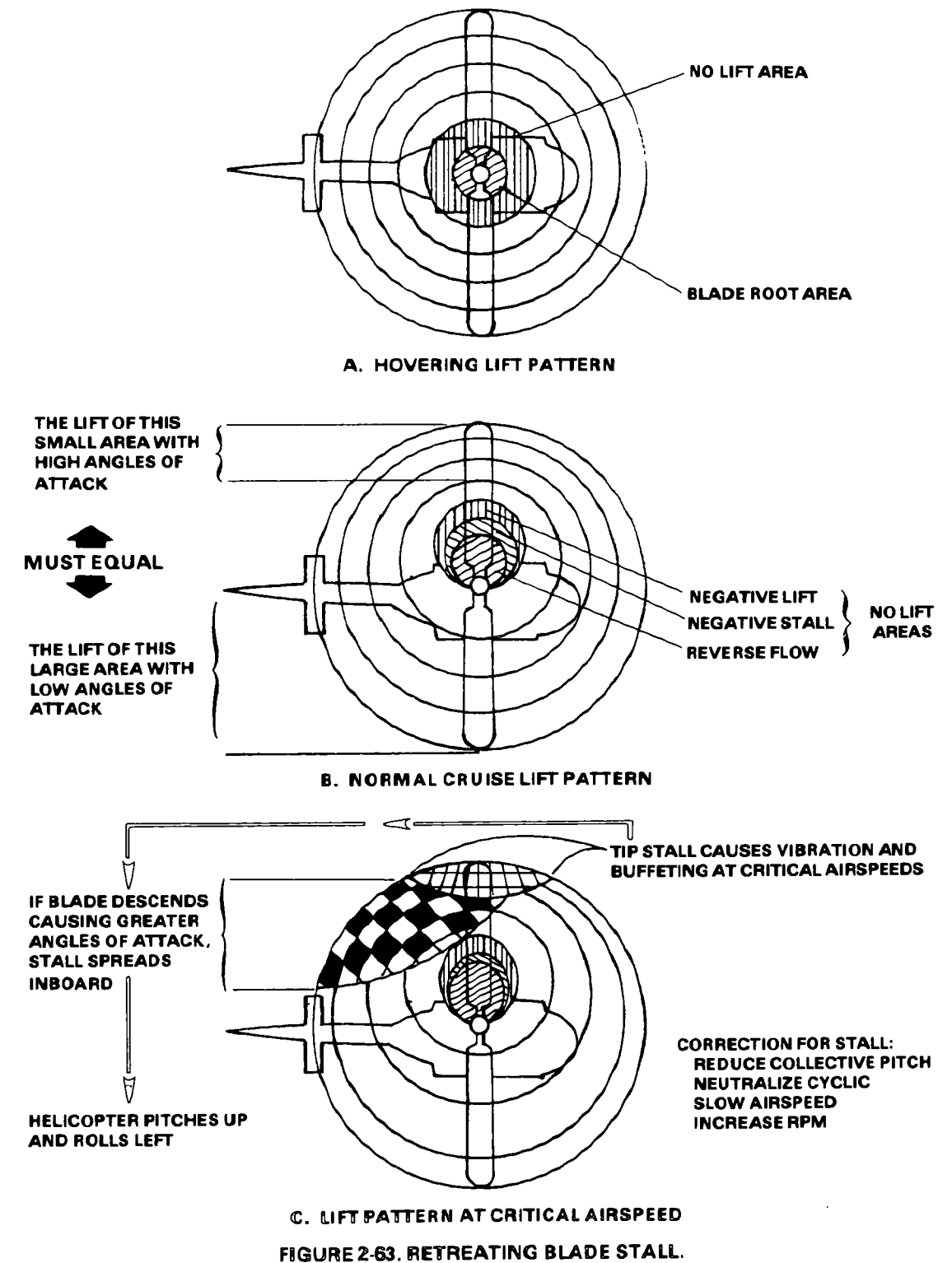
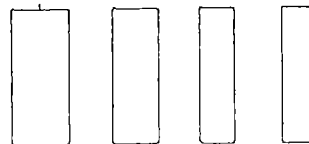


Figure 2-64 shows a rotor disk that has reached a stall condition on the retreating side. It is assumed that the stall angle of attack for this rotor system is 14° . Distribution of angle of attack along the blade is shown at eight positions in the rotor disk. Although the blades are twisted and have less pitch at the tip than at the root, angle of attack is higher at the tip because of induced airflow.

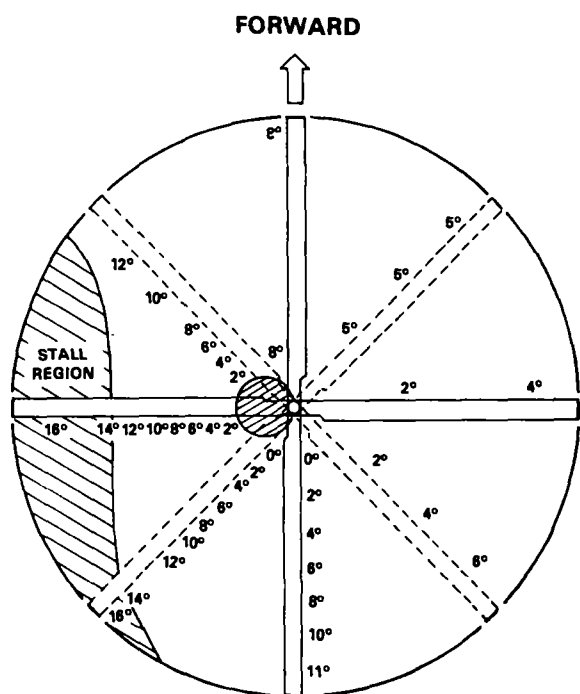


FIGURE 2-64. ANGLE OF ATTACK DISTRIBUTION DURING RETREATING BLADE STALL.

☐ **Effects.** Upon entry into blade stall, the first effect is generally a noticeable vibration of the helicopter. This is followed by a rolling tendency and a tendency for the nose to pitch up. The tendency to pitch up may be relatively insignificant for helicopters with semirigid rotor systems due to pendular action. If the cyclic stick is

held forward and collective pitch is not reduced or is increased, this condition becomes aggravated; the vibration greatly increases, and control may be lost. By being familiar with the conditions which lead to blade stall, the aviator should realize when he is flying under such circumstances and should take corrective action.

The major warnings of approaching retreating blade stall conditions are—

- Abnormal vibration.
- Pitchup of the nose.
- Tendency for the helicopter to roll in the direction of the stalled side.

When operating at high forward speeds, the following conditions are most likely to produce blade stall:

- High blade loading (high gross weight).
- Low rotor RPM.
- High density altitude.
- Steep or abrupt turns.
- Turbulent air.

☐ **Corrective Actions.** When flight conditions are such that blade stall is likely, extreme caution should be exercised when maneuvering. An abrupt maneuver such as a steep turn or pullup may result in dangerously severe blade stall. Aviator control and structural limitations of the helicopter would be threatened.

Blade stall normally occurs when airspeed is high. To prevent blade stall, the aviator must fly slower than normal when—

- The density altitude is much higher than standard.
- Carrying maximum gross loads.
- Flying high drag configurations, floats, external stores, weapons, speakers, floodlights, sling loads, etc.
- The air is turbulent.

When the aviator suspects blade stall, he can possibly prevent its occurrence by sequentially—

- Reducing power.
- Reducing airspeed.
- Reducing "G" loading during maneuvering.
- Increasing RPM toward upper limit.
- Checking pedal trim.

In severe blade stall, the aviator loses control. The helicopter will pitch up violently and roll to the left. The only corrective action, then, is to accomplish procedures as indicated previously to shorten the duration of the stall and regain control.

COMPRESSIBLE FLOW

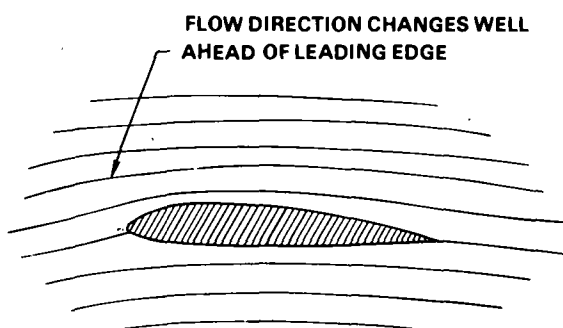
As helicopter speeds increase and missions become more varied, the helicopter pilot must learn to cope with the effects of compressibility encountered in high speed airflow. Earlier we described the qualities of incompressible airflow and said at low speeds it was analogous to the flow of water, hydraulic fluid, or any other incompressible fluid. It is this way because at low speeds air experiences relatively small changes in pressure with only *negligible* changes in *density*. However, at high speeds, the pressure changes that take place are larger and result in significant *air density* changes. The study of airflow at high speeds must account for these changes in *air density*. It must also consider that the air is compressible and that there will be compressibility effects.

The dominating factor in high speed airflow is the *speed of sound*. Speed of sound is the rate at which small pressure disturbances will be propagated through the air and this propagation speed is solely a function of air temperature. Figure 2-65 shows the variation of the speed of sound in the standard atmosphere.

ALTITUDE	TEMPERATURE		SPEED OF SOUND
	°F	°C	
Feet			Knots
See Level	59.0	15.0	861.7
5,000	41.2	5.1	850.3
10,000	23.3	-4.6	838.6
15,000	5.5	-14.7	826.7
20,000	-12.3	-24.6	814.6
25,000	-30.2	-34.5	802.2
30,000	-48.0	-44.4	789.6
35,000	-65.8	-54.3	778.6
40,000	-89.7	-66.5	773.8
50,000	-89.7	-66.5	773.8
60,000	-89.7	-66.5	773.8

FIGURE 2-65. VARIATION OF TEMPERATURE AND SPEED OF SOUND WITH ALTITUDE.

SUBSONIC FLOW PATTERN



SUPersonic FLOW PATTERN

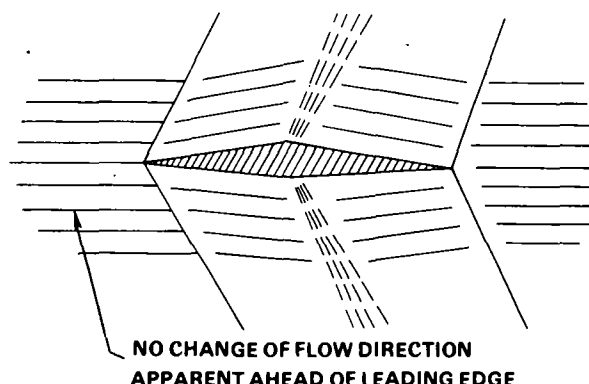


FIGURE 2-66. COMPARISON OF SUBSONIC AND SUPersonic FLOW PATTERNS.

If the airfoil is traveling at some speed above the speed of sound, the airflow ahead of it will not be influenced by the pressure field, because pressure disturbances cannot be propagated ahead of the airfoil. Thus, as the speed nears the speed of sound, a compression wave forms at the leading edge and all changes in velocity and pressure take place sharply and suddenly. The airflow ahead of the airfoil is not influenced until the air particles are suddenly forced out of the way by the concentrated pressure wave set up by the airfoil. A typical supersonic airflow is shown in figure 2-66.

As an airfoil moves through the air, velocity and pressure changes occur which create pressure changes in the airflow surrounding the airfoil. These pressure changes are propagated through the air at the speed of sound. If the airfoil is traveling at low speed, the pressure disturbances are propagated ahead of it. The airflow immediately ahead of the airfoil is influenced by the pressure field on the airfoil. Evidence of how this pressure field influences the flow ahead of an airfoil

traveling at low speed is shown in figure 2-66.

It should become apparent that all compressibility effects depend upon the relationship of blade airspeed to the speed of sound. The term used to describe this relationship is the Mach number (M). This term is the relationship of the true airspeed to the speed of sound.

$$M = \frac{V}{a}$$

where: M = Mach number

V = true airspeed, knots

a = speed of sound, knots

$$= a_0 \sqrt{\theta}$$

a_0 = speed of sound at 288°K (15°C) is 661.7 knots

θ = temperature ratio

$$= T/T_0$$

Compressibility effects are not limited to speeds at and above the speed of sound. The aerodynamic shape of an airfoil causes local flow velocities which are greater than the blade speed. Thus, a blade can experience compressibility effects at speeds well below the speed of sound. Since there is the possibility of having *both* subsonic and supersonic flows existing on a blade, it is necessary to define certain regimes of flight as follows:

Subsonic - Mach numbers below 0.75

Transonic - Mach numbers from 0.75 to 1.20.

Supersonic - Mach numbers from 1.20 to 5.00

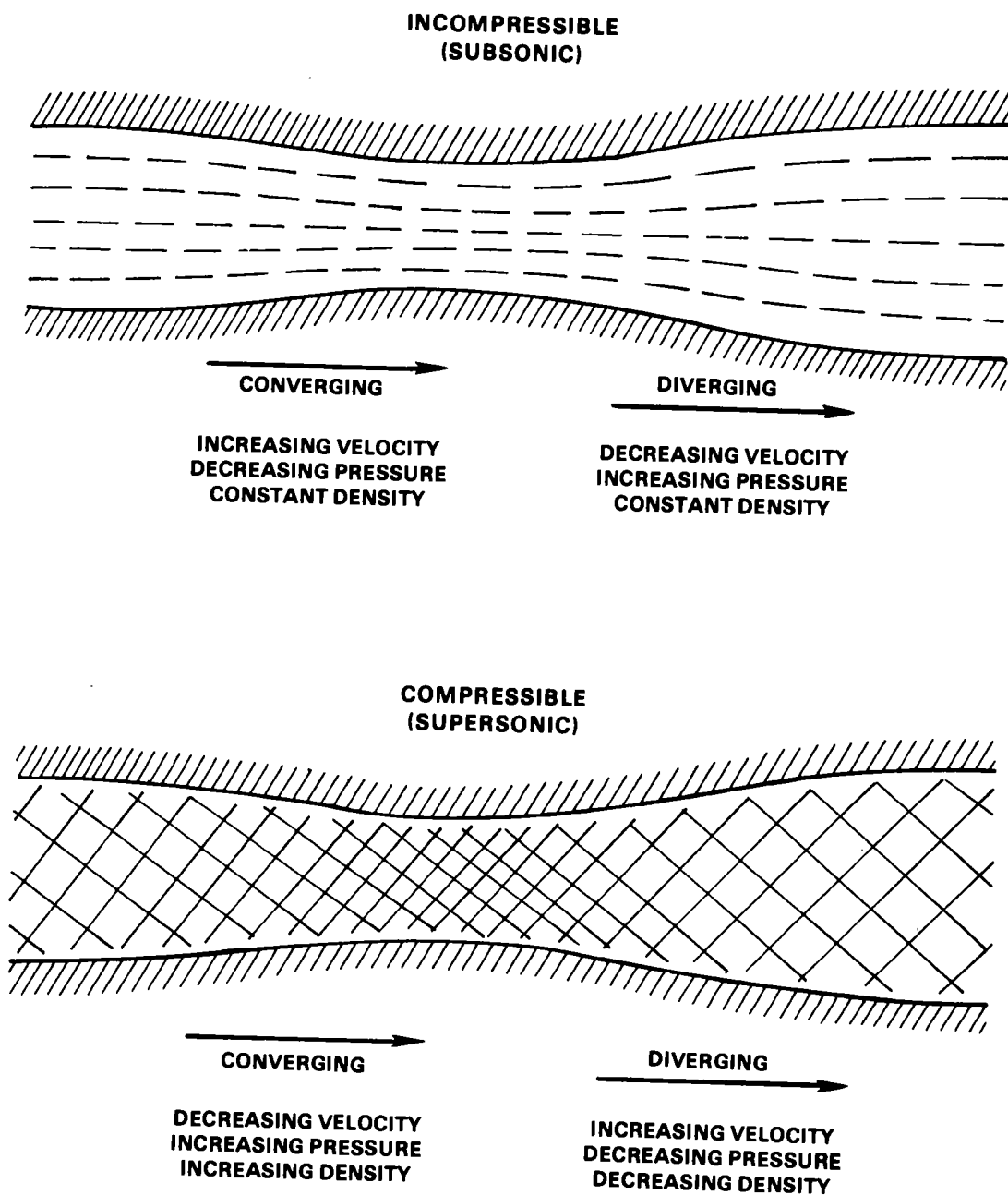
Although the Mach numbers used to define these regimes of flight are approximate, it is important to appreciate the types of flow existing in each area. In the subsonic regime, it is likely that pure subsonic airflow exists on all parts of the blade. In the transonic regime, it is very probable that flow on the blades may be partly subsonic and partly supersonic.

The principal differences between subsonic and supersonic flow are due to the *compressibility* of the supersonic flow. Figure 2-67 shows a comparison of incompressible and compressible flow through a closed tube. In both cases, assume the mass flow at any station along the tube is constant.

The example of subsonic incompressible flow is simplified by the fact that the *density* of flow is constant throughout the tube. As the flow approaches a constriction and the streamlines converge, velocity increases as static pressure decreases. In other words, a convergence of the tube requires an increasing velocity to accommodate the continuity of flow. Also, as the subsonic incompressible flow enters a diverging section of the tube, velocity decreases and static pressure increases while density remains unchanged. The behavior of subsonic incompressible flow is that a convergence causes expansion (decreasing pressure), while a divergence causes compression (increasing pressure).

The example of supersonic compressible flow is complicated by the fact that the variations of flow density are related to the changes in velocity and static pressure. The behavior of supersonic compressible flow is that a convergence causes compression, while a divergence causes expansion. Thus, as the supersonic compressible flow approaches a constriction and the streamlines converge, velocity decreases and static pressure increases. Continuity of mass flow is maintained by the increase in flow *density* which accompanies the decrease in velocity. As the supersonic compressible flow enters a diverging section of the tube, velocity increases, static pressure decreases, and density decreases to accommodate the condition of continuity.

Three significant differences emerge from the comparison between supersonic compressible and subsonic incompressible flow.



**FIGURE 2-67. COMPARISON OF COMPRESSIBLE AND INCOMPRESSIBLE FLOW
THROUGH A CLOSED TUBE.**

☐ Compressible flow includes the additional variable of flow density.

☐ Convergence of flow causes expansion of incompressible flow, but compression of compressible flow.

☐ Divergence of flow causes compression of incompressible flow, but expansion of compressible flow.

An airfoil in subsonic flight which is producing lift will have local velocities on the surface which are greater than the free stream velocity. Hence, compressibility effects can be expected to occur at flight speeds less than the speed of sound. The transonic regime of flight provides the opportunity for mixed subsonic and supersonic flow and accounts for the first significant effects of compressibility.

Consider the conventional airfoil shape shown in figure 2-68. If this airfoil is at a flight Mach number of 0.50 and a slight positive angle of attack the maximum local velocity on the surface will be greater than the blade speed, but most likely less than sonic speed. Assume that an increase in blade Mach number to 0.72 would produce first evidence of local sonic flow. This condition of flight is the highest blade speed possible without supersonic flow, and is termed the *critical* Mach number. By definition, critical Mach number is the free stream Mach number which produces first evidence of local sonic flow. Therefore, shock waves, buffet, and airflow separation take place above critical Mach number.

As critical Mach number is exceeded, an area of supersonic airflow is created and a normal shock wave forms as the boundary between the supersonic flow and the subsonic flow on the aft portion of the airfoil surface. The acceleration of the airflow from subsonic to supersonic is smooth and without shock waves if the surface is smooth and the transition gradual. However, the transition of airflow from supersonic to subsonic is always accompanied by a shock wave. When there is no change in direction of the airflow, the wave form is a normal shock wave.

The normal shock wave is detached from the leading edge of the airfoil and is perpendicular to the upstream flow. The flow immediately behind the wave is subsonic. Figure 2-69 illustrates how an airfoil at high subsonic speeds has local flow velocities which are supersonic. As the local supersonic flow moves aft, a normal shock wave forms, slowing the flow to subsonic. A supersonic airstream passing through a *normal* shock wave will experience these changes:

☐ The airstream is slowed to subsonic; the local Mach number behind the wave is about equal to the reciprocal of the Mach number ahead of the wave—e.g., if Mach number ahead of the wave is 1.25, the Mach number of the flow behind the wave is approximately 0.80.

☐ The airflow direction immediately behind the wave is unchanged.

☐ The static pressure of the airstream behind the wave is increased greatly.

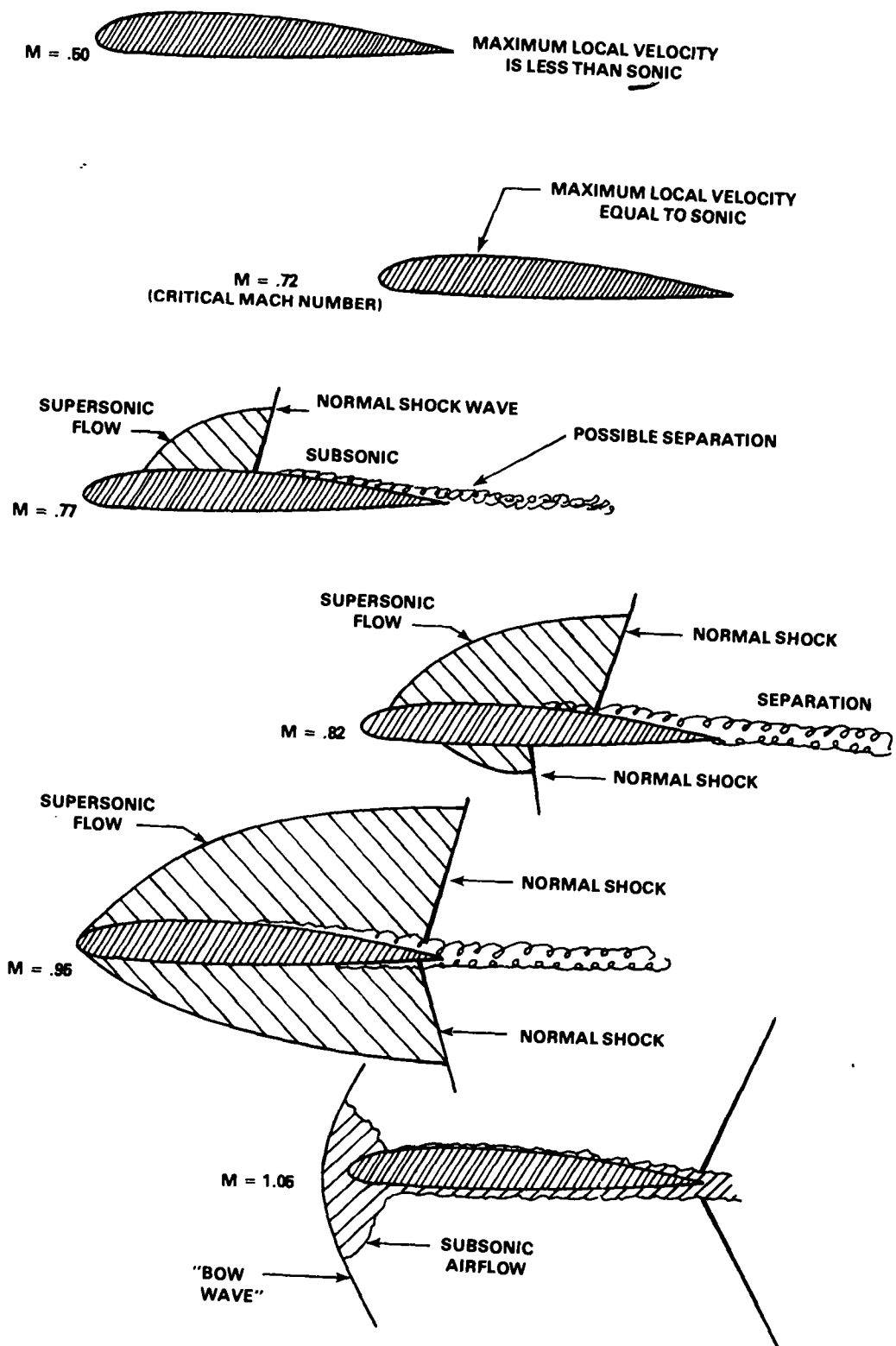


FIGURE 2-68. TRANSONIC FLOW PATTERNS.

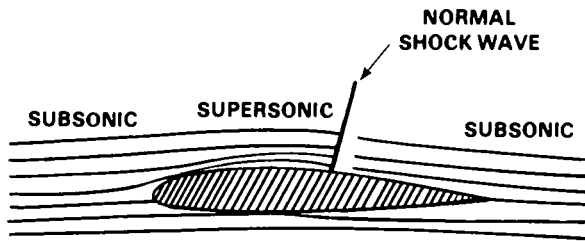


FIGURE 2-69. NORMAL SHOCK WAVE FORMATION.

- ☐ The density of the airstream behind the wave is increased greatly.
- ☐ The energy of the airstream indicated by total pressure is greatly reduced (dynamic plus static). The normal shock wave is very wasteful of energy.

As stated in the preceding paragraph, one of the principal effects of the normal shock wave is to produce a large increase in the static pressure of the airstream behind the wave. If the shock wave is strong, the boundary layer may separate. At speeds only slightly beyond critical Mach number, the shock wave formed is not strong enough to cause separation or any noticeable change in aerodynamic forces. However, a larger increase in speed above critical Mach number sufficient to form a strong shock wave can cause separation of the boundary layer and produce sudden changes in aerodynamic forces. Such a flow condition is shown in figure 2-68 by the flow pattern for $M = 0.77$. Notice a further increase in Mach number to 0.82 enlarges the supersonic area on the upper surface and forms an additional area of supersonic flow and normal shock wave on the lower surface.

As the blade speed approaches the speed of sound, the areas of supersonic flow enlarge and the shock waves move nearer the trailing edge (fig 2-68, $M = 0.95$). The boundary layer may remain separated or may reattach, depending upon airfoil shape and angle of attack. When the blade speed exceeds the speed of sound the "bow" wave forms at the leading edge. This typical flow pattern is shown in figure 2-68 by the drawing for $M = 1.05$. If speed is increased to some higher supersonic value, all oblique portions of the waves incline more greatly; and the detached normal shock portion of the bow wave moves closer to the leading edge.

Airflow separation induced by shock wave formation can create significant variations in aerodynamic force coefficients of the airfoil section. When the blade speed exceeds the critical Mach number some typical effects on an airfoil section are:

- ☐ An increase in the section drag coefficient for a given section lift coefficient.
- ☐ A decrease in section lift coefficient for a given section angle of attack.
- ☐ A change in section pitching moment coefficient. A comparison of drag coefficient versus Mach number for a constant lift coefficient is shown in figure 2-70. Note the sharp increase in the drag coefficient. This point is termed the "force divergence" Mach number and usually exceeds the critical Mach number by about 5 to 10 percent.

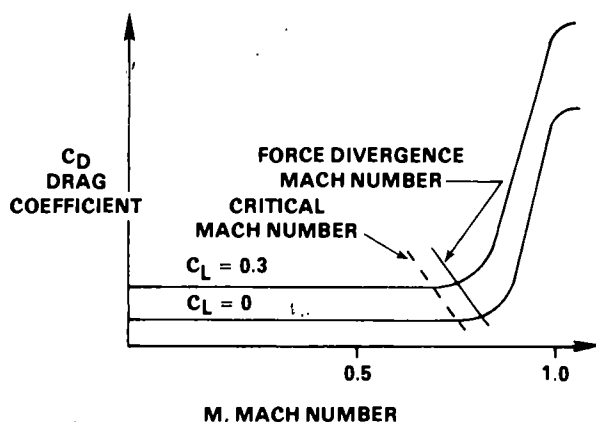


FIGURE 2-70. COMPRESSIBILITY DRAG RISE.

Since the speed of the helicopter is added to the speed of rotation of the advancing blade, the highest relative velocities occur at the tip of the advancing blade. When the Mach number of the tip section of the advancing blade exceeds the critical Mach number for the rotor blade section, compressibility effects result. The principal effects of compressibility are the large increase in drag and the rearward shift of the airfoil aerodynamic center. Compressibility effects on the helicopter increase the power required to maintain rotor RPM and cause rotor roughness, vibration, cyclic shake, and an undesirable structural twisting of the blade.

Compressibility effects become more severe at higher lift coefficients (higher blade angles of attack) and higher Mach numbers. The following operating conditions represent the most adverse compressibility conditions:

- ☐ High airspeed.
- ☐ High rotor RPM.

☐ High gross weight.

☐ High density altitude.

☐ Low temperature. The speed of sound is proportional to the square root of the absolute temperature. Therefore, sonic velocity will be more easily obtained at low temperatures when the sonic speed is lower.

☐ Turbulent air. Sharp gusts momentarily increase the blade angle of attack and thus lower the critical Mach number to the point where compressibility effects may be encountered on the blade.

Compressibility effects will vanish if blade pitch is decreased. The similarities in the critical conditions for retreating blade stall and compressibility should be noticed, but one basic difference must be appreciated. Compressibility occurs at high RPM while retreating blade stall occurs at low RPM. With the exception of RPM control, recovery technique is identical for both.

BLADE LEAD AND LAG

Fully articulated rotors have hinged blades that are free to move fore and aft in the plane of rotation independent of the other blades in the system. Movement about the hinge avoids bending stresses and is dampened by a drag damper to avoid undesirable oscillations. When the helicopter moves horizontally, the blade pitch angle continually changes throughout each revolution of the rotor to overcome dissymmetry of lift. Pitch angle variation causes changes in blade drag which makes the blade lead or lag about the drag hinge.

Another force, called *Coriolis force*, causes blades to lead and lag. Coriolis was a French mathematician who made a study of motion in a plane of rotation caused by periodic mass forces. This type of motion is governed by the law of conservation of angular momentum. The law states that a rotating body will continue to rotate with the same rotational velocity until some external force is applied to change the speed of rotation. Changes in angular velocity (angular acceleration or deceleration) will take place if the mass of a rotating body is moved closer to, or further from, the axis of rotation. If the mass is moved closer to the axis of rotation, the mass will accelerate. If the mass is moved away from the axis of rotation, it will decelerate. A common example that illustrates this law is the ice skater performing a rotating movement. The skater begins rotating on one foot with both arms and one leg extended out from the body. Rotation is relatively slow until the skater moves both arms and the leg in close to the body (axis of rotation). Suddenly rotational speed increases dramatically because the skater's center of mass has moved closer to the axis of rotation. Mass did not change and no external force was applied, so velocity had to increase.

Applying the principle of Coriolis force to a rotating helicopter blade, it may be stated:

□ A mass moving radially outward on a rotating disk will exert a force opposite to rotation (deceleration).

□ A mass moving radially inward on a rotating disk will exert a force in the direction of rotation (acceleration).

Consider the helicopter stationary on the ground in a no-wind condition with the rotor turning. The distance from the blade center of gravity to the shaft axis is constant throughout a complete blade revolution (a, b, fig 2-71). If the cyclic stick is moved laterally, the rotor blade will climb on one side of the disk and descend on the other side to produce a changed disk attitude. Since the helicopter is stationary on the ground, the shaft axis about which the blades are turning has not moved. The distance from the blade center of gravity to the shaft axis changes continuously through each 360° of travel (c, d, fig 2-71). On the side where the blade climbs, the radius (d, fig 2-71) decreases and the blade accelerates (leads). The opposite side has a descending blade and an increasing radius (c, fig 2-71), causing the blade to decelerate (lag).

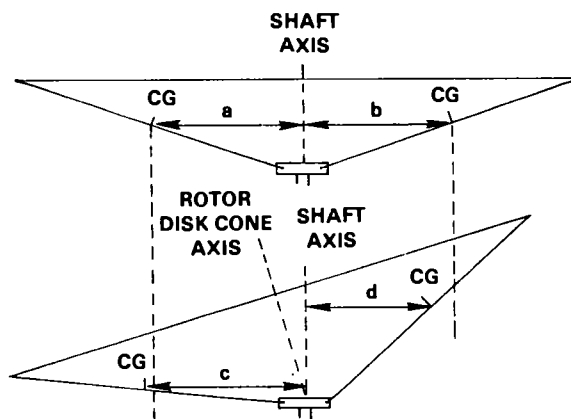


FIGURE 2-71. RADIUS CHANGE OF BLADE CG RELATIVE TO DISK ATTITUDE.

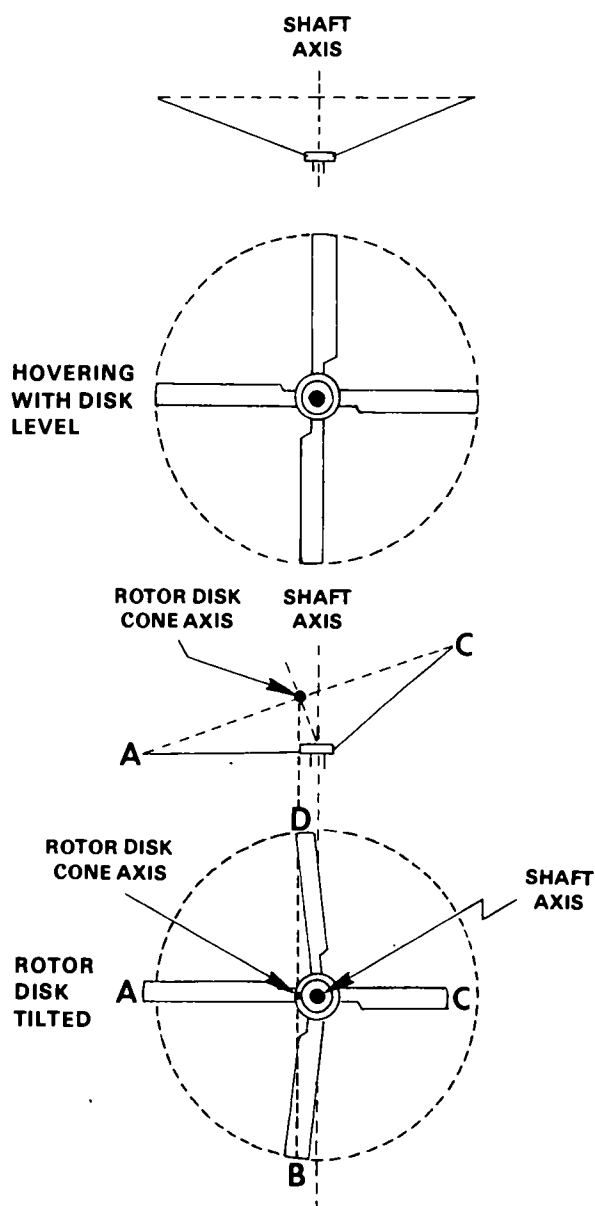


FIGURE 2-72. LEAD AND LAG.

Figure 2-72 illustrates lead and lag of a four-bladed rotor, using a side view and a top view of the rotor system. Note that the blades are evenly spaced 90° apart on the level disk. The tilted rotor disk has uneven spacing between the blades because of lead and lag. At point A, figure 2-72, the blade

has descended and begins to decelerate. As it decelerates, it lags enough to align with the rotor disk cone axis at point B. At point C the blade has climbed which decreases the distance from center of gravity (CG) to shaft axis resulting in an acceleration force. At D the blade is leading as a result of acceleration and has moved ahead to align with the cone axis. This phenomenon occurs whenever the shaft axis and cone axis are separated by a tilted rotor disk.

CYCLIC CONTROL STICK POSITION VERSUS AIRSPEED RELATIONSHIP

The cyclic control stick plot (fig 2-73) is an engineering graph made by a stylus placed on the cyclic stick. This permits a graphic plot and a record of stick positions required to maintain various steady-state airspeeds. The stick plot may cover the entire flight envelope, starting from the

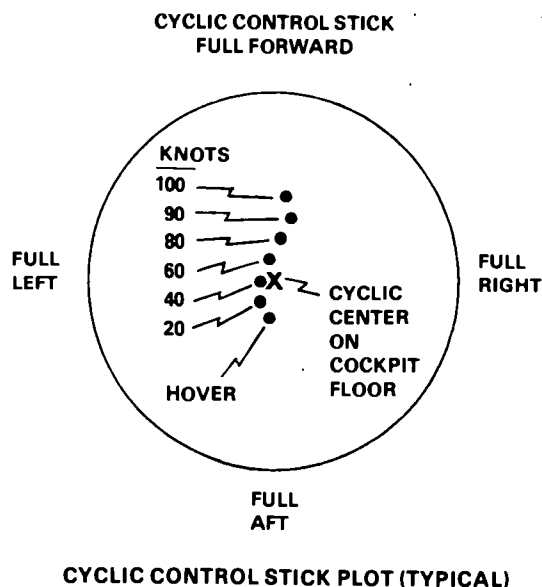


FIGURE 2-73. CYCLIC CENTER OF CONTROL SHIFT.

hover and continuing on to "velocity never exceed" (V_{ne}) airspeeds, and perhaps blade stall. The stick plot was originally used to record cyclic travel for initial certification of newly designed or extensively modified helicopters.

The cyclic stick action required by the aviator for control of attitude, for changing attitudes, and for the prevention and correction of dissymmetry of lift is as follows:

□ The aviator applies slight cyclic control stick pressures and counterpressures around the hover cyclic center to maintain the hover and to correct deviations of the rotor from the level attitude.

□ The aviator applies slight pressures and counterpressures while rotating to an acceleration attitude; then additional slight corrections are made to hold the acceleration attitude constant.

□ As the airspeed approaches the next higher speed zone (each 10 to 15 knots), the aviator must reposition the cyclic stick further forward as the center of control shifts (brought about by the correction required for dissymmetry of lift, fig 2-73).

□ At any forward steady-state airspeed (e.g., 80 knots), the aviator must use constant slight corrective pressures around the 80-knot cyclic center to hold the specific attitude for 80 knots.

□ If the aviator applies a slight aft cyclic stick to assume a deceleration attitude, the cyclic stick returns to the 80-knot setting. Then the aviator applies corrective pressures to hold the deceleration attitude constant.

□ To hold the same decelerating attitude as the airspeed actually reduces (e.g., to 60 knots), the aviator must reposition his center of control rearward as shown in figure 2-73.

□ During a flight from the hover to V_{ne} values and back to termination of flight at a hover, the cyclic control center shifts as airspeed is changed. Therefore, the aviator should be more aware of the specific attitude as the real measure of control, rather than place any overdependence on the methods based upon feel, touch, and/or coordination.

EFFECT OF ROTOR SYSTEM DESIGN ON WEIGHT AND BALANCE LIMITATIONS

Weight and balance limitations change greatly with different main rotor system configurations.

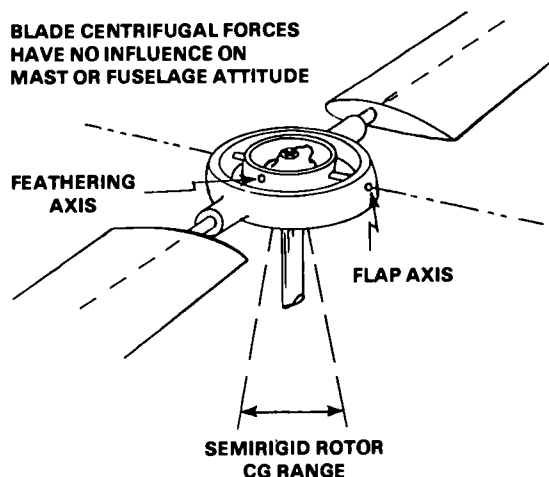


FIGURE 2-74. SEMIRIGID ROTOR SYSTEM.

□ A semirigid rotor system only supplies support and mobility to the free hanging pendulous mass of the fuselage (fig 2-74). Therefore, it has a limited allowance for center of gravity travel (fig 2-76).

□ In a fully articulated rotor system with offset hinges (fig 2-75), blade centrifugal forces assist the fuselage to support a wide-range center of gravity travel (fig 2-76).

□ A rigid (hingeless) rotor system provides rotor rigidity in which centrifugal blade forces hold the fuselage level throughout a very wide center of gravity tolerance laterally and fore and aft (fig 2-76).

□ A multirotor system using differential collective has the greatest allowance for center of gravity travel (fig 2-76).

BLADE CENTRIFUGAL FORCES APPLIED TO OFFSET HINGES HAVE STRONG INFLUENCE ON MAST AND FUSELAGE ATTITUDE.

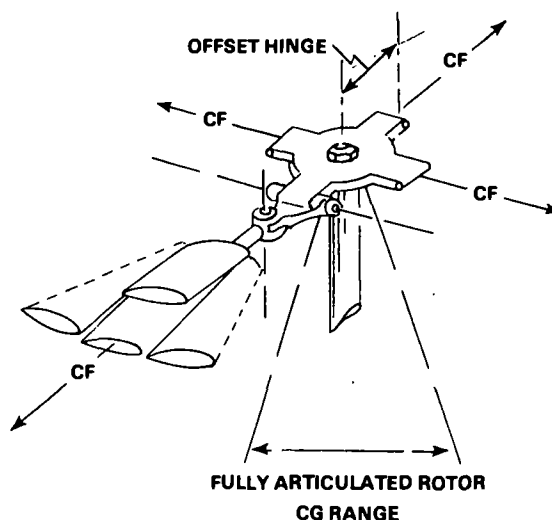


FIGURE 2-75. FULLY ARTICULATED ROTOR SYSTEM WITH OFFSET HINGES.

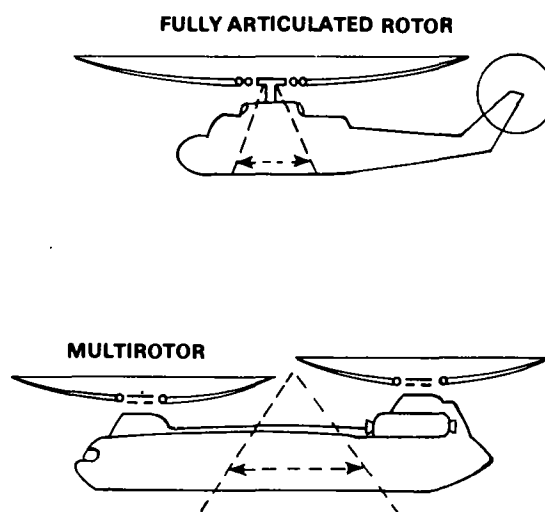
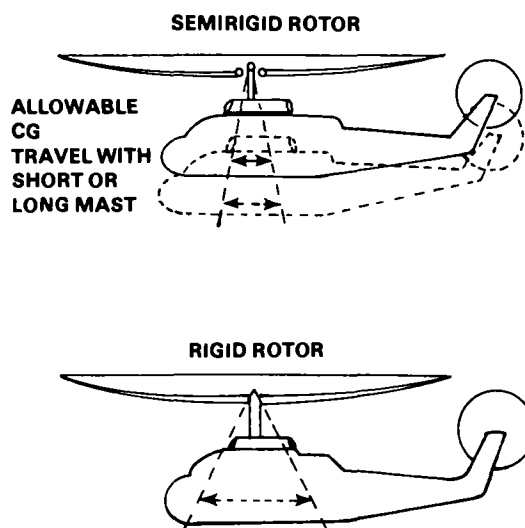


FIGURE 2-76. EFFECT OF ROTOR SYSTEM ON CENTER OF GRAVITY TRAVEL.

DANGER OF EXCEEDING CENTER OF GRAVITY LIMITS

The permissible center of gravity travel is very limited in many helicopters. The weight of the crew, fuel, passengers, cargo, etc., must be carefully distributed to prevent the helicopter from flying with a dangerous nose-low, nose-high, or lateral (side-low) attitude. If such *CG* attitudes exceed the limits of cyclic controls, the rotor will be forced to follow the tilt of the fuselage, and control may be lost.

The helicopter will then move at a speed and direction proportionate to the tilt of the rotor system. The amount of cyclic control the aviator can apply to level the rotor system could be limited by the manner in which the helicopter is loaded. If a helicopter is loaded "out of *CG* limits" (①, fig 2-77), the aviator may find that when he applies corrective cyclic control (②, fig 2-77) as far as it will go, the helicopter attitude will remain low in the

direction *CG* limits are exceeded. He will not be able to level the helicopter to decelerate and land. This creates an extremely dangerous situation (③, fig 2-77).

In newer helicopter designs, efforts have been made to place the loading compartment directly under the main rotor mast to minimize *CG* travel effects. However, the aviator must still exercise care in loading, and arrange his load to assure that it is centered within allowable *CG* travel limits of his helicopter as prescribed in the Operator's Manual for the particular helicopter.

The final check for *CG* is made operationally just prior to the takeoff to a hover.

- ☐ In flight, a *CG* centered in the forward portion of the envelope will result in relatively nose-low attitudes.
- ☐ An aft *CG* condition will result in relatively nose-high flight attitudes.

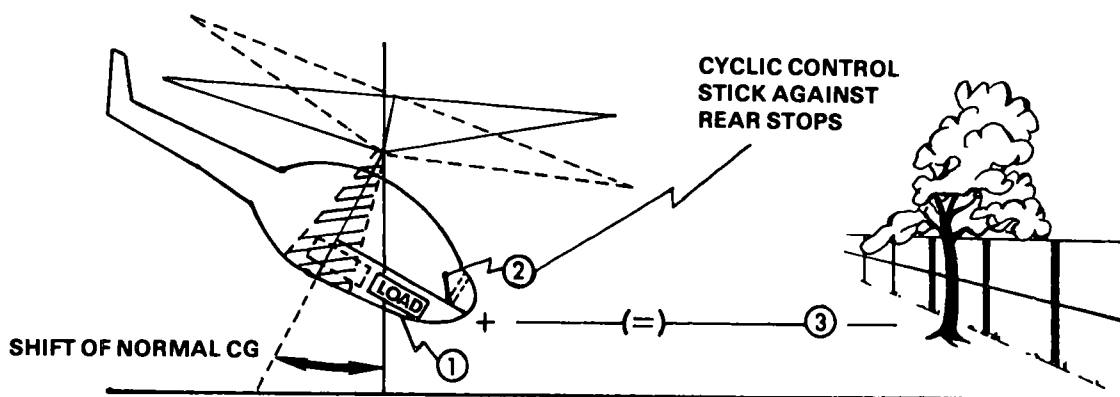


FIGURE 2-77. EXCESSIVE LOADING FORWARD OF THE CENTER OF GRAVITY.

□ A lateral CG displacement will result in a relatively right-side or left-side low flight attitude. The correct procedure then is to cruise with one side low.

□ A common error is to level the lateral CG attitude by use of a "forward-slip" (excess trim pedal). This causes a broad-side wind and a lateral drag that levels the fuselage. This drag costs more power at cruise and results in less range. In autorotation, this fuselage drag would result in a greater rate of descent and a shortened gliding distance.

PENDULAR ACTION

Since the fuselage of the helicopter is suspended from a single point and has considerable mass, it is free to oscillate laterally or longitudinally in the same way as a pendulum.

□ Normally, the fuselage follows the rules which govern pendulums, balance, and inertia.

□ The rotor systems follow rules governing aerodynamics, dynamics, and gyroscopics.

□ Fortunately, these two unrelated systems form a close and compatible partnership which normally avoids serious conflict.

Other factors which affect the relationship of the rotor system and fuselage are:

□ *Overcontrolling.* Overcontrolling results when aviator cyclic control stick movements cause rotor tip changes that are not reflected in corresponding fuselage attitude changes. Correct aviator cyclic control movements (free of overcontrol) cause the rotor tip-path and the fuselage to move in unison.

Erratic airspeed and altitude control may not be due to overcontrolling, but may result from a lack of knowledge of attitude flying techniques.

□ *Cyclic control response (single rotor helicopter).* The rotor's response to cyclic

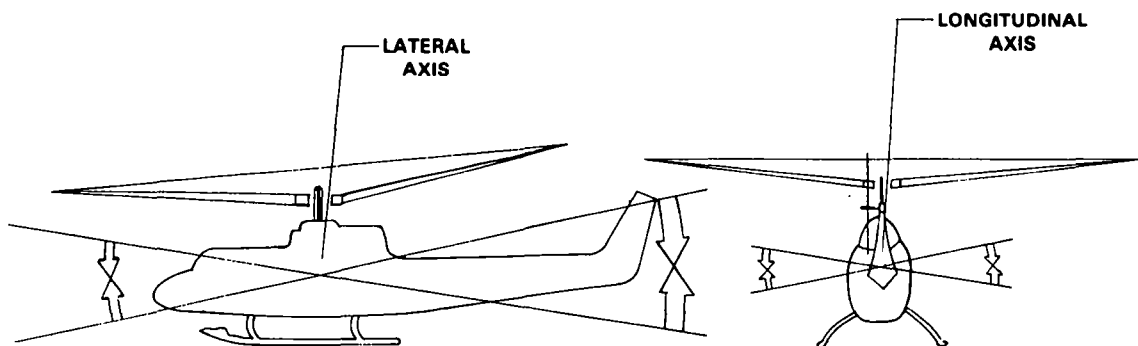


FIGURE 2-78. CYCLIC CONTROL RESPONSE AROUND THE LONGITUDINAL AXIS AND THE LATERAL AXIS.

control input has no lag. The rotor blades respond instantly to the slightest touch of the cyclic control.

There is a noticeable difference in the fuselage response to lateral cyclic compared to fore and aft cyclic applications. Normally it requires considerably more fore and aft cyclic movement to achieve the same fuselage response as is achieved from an equal amount of lateral cyclic. This is not a lag in rotor response. It is due to more fuselage inertia around the lateral axis as compared to fuselage inertia around the longitudinal axis (fig 2-78). For semirigid helicopters, the normal corrective device is the addition of a synchronized elevator attached to the tail boom and operated by the cyclic stick. This elevator forces the fuselage to follow the rotor at normal flight airspeeds; however, it is ineffective at slow airspeeds.

☐ *Shift of attitude due to fuel expenditure.* Fuel cells normally have a slight aft CG. As fuel is used there is a slight shift to a more nose-low attitude.

Due to fuel expenditure and a lighter fuselage, cruise attitudes tend to shift slightly lower. As fuel loads are reduced, the lighter fuselage is affected more by drag which results in a more nose-down attitude. Therefore, there is a slight shift to a more nose-low attitude during the flight period.

FUSELAGE ADD-ONS, FIXES, AND MODIFICATIONS

Fuselage nose-low attitude at cruise is typical of the single rotor helicopter.

☐ The causes of this condition are—

- The fuselage attitude aligning itself to the tilted rotor disk at cruise airspeeds.

- Helicopter propulsion thrust is applied horizontally from the aerodynamic center of the main rotor; therefore, the total flat plate drag of the fuselage (centered many feet below the rotor) will cause an additional nose-low influence.

☐ The usual corrective measures are—

- Mounting the transmission in the fuselage with some degree of forward tilt presets the rotor system at the cruise airspeed tilt angle, while providing a level fuselage at cruise airspeeds.

- Adding a horizontal stabilizer or synchronized elevator on the tail boom. This will counteract the fuselage drag by holding the tail down and the fuselage level in cruise flight.

Fuselage add-on devices, external stores, or sling loads all perform useful services during certain modes of flight. However, these add-on surfaces or devices often add flat plate drag and develop troublesome side effects at higher or lower airspeeds, or hovering in crosswind/downwind conditions. Fuselage add-on devices include—

☐ Airfoil-shaped tail rotor pylons.

☐ Fixed or controllable elevators.

☐ Fixed-wing panels (experimental).

☐ Ventral fins and vertical stabilizers.

- ☐ Spoilers.
- ☐ Amphibious gear or floats.
- ☐ Dust or spray rigs.
- ☐ External pods.
- ☐ External ordnance and related hardware.
- ☐ Guns, cameras, or floodlights.
- ☐ Sling loads.

Additional problems of the pendulous fuselage are—

- ☐ Weather vane effect in crosswind hovering.
- ☐ Very poor inherent pedal trim (fuselage often drags somewhat sideward in flight due to a lack of pilot assist trim device).
- ☐ The possibility of rotor blade strikes on the fuselage. Poorly controlled slope operations or run-on landings with hard jolting touchdowns and poor heading control cause unacceptable force moments (or fuselage attitudes) that exceed main rotor/fuselage compatibility. These impacts increase the possibility of rotor blade strikes on the tail boom or the ground.

SETTLING WITH POWER

Settling with power is a condition of powered flight where the helicopter settles in its own downwash. The condition may also be referred to as the *vortex ring state*.

Conditions conducive to settling with power are a vertical or near vertical descent of at least 300 feet per minute and low forward speed. The rotor system must also be using some of the available engine power (from 20 to 100 percent) with insufficient power available to retard the sink rate. These conditions occur during approaches with a tailwind or during formation approaches when some aircraft are flying in turbulence from other aircraft.

Under the conditions described above, the helicopter may descend at a high rate which exceeds the normal downward induced flow rate of the inner blade sections. As a result, the airflow of the inner blade sections is upward relative to the disk. This produces a *secondary* vortex ring in addition to the normal tip vortex system. The secondary vortex ring is generated about the point on the blade where airflow changes from up to down. The result is an unsteady turbulent flow over a large area of the disk which causes loss of rotor efficiency even though power is still supplied from the engine.

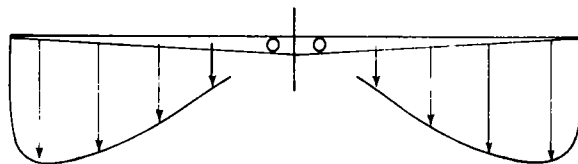


FIGURE 2-79. INDUCED FLOW VELOCITY DURING HOVERING FLIGHT.

Figure 2-79 shows the induced flow along the blade span during hovering flight. Downward velocity is highest at the blade tip where blade airspeed is highest. As blade airspeed decreases nearer the disk

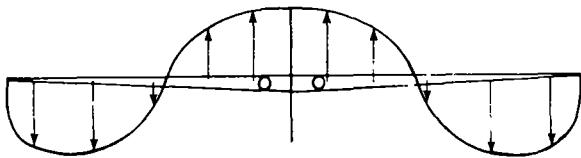


FIGURE 2-80. INDUCED FLOW VELOCITY DURING VORTEX RING STATE.

center, downward velocity is less. Figure 2-80 shows the induced airflow velocity pattern along the blade span during a descent conducive to settling with power. The descent is so rapid that induced flow at the inner portion of the blades is upward rather than downward. The upflow caused by the descent has overcome the downflow produced by blade rotation. If the helicopter descends under these conditions, with insufficient power to slow or stop the descent, it will enter the vortex ring state (fig 2-81). During the vortex ring state, roughness and loss of control is experienced because of the turbulent rotational flow on the blades and the unsteady shifting of the flow along the blade span.

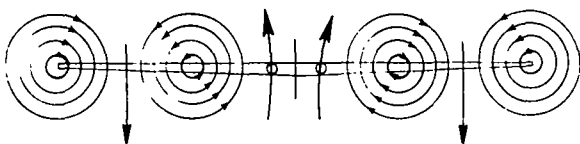


FIGURE 2-81. VORTEX RING STATE.

Figure 2-82 shows the relationship of horizontal speed versus vertical speed for a typical helicopter in a descent. Straight lines emanating from the upper left corner are lines of constant descent angle. Superimposed on this grid are flow state regions for the typical helicopter. From this illustration, several conclusions regarding the vortex ring state can be drawn.

□ The vortex ring state can be completely avoided by descending on flight-paths shallower than about 30° (at any speed).

□ For steeper approaches, vortex ring state can be avoided by using a speed either faster or slower than the area of severe turbulence and thrust variation.

□ At very shallow angles of descent, the vortex ring wake is shed behind the helicopter.

□ At steep angles, the vortex ring wake is below the helicopter at slow rates of descent and above the helicopter at high rates of descent.

Power settling is an unstable condition. If allowed to continue, the sink rate will reach sufficient proportions for the flow to be entirely up through the rotor system. If continued, the rate of descent will reach extremely high rates. Recovery may be initiated during the early stages of power settling by putting on a large amount of excess power. During the early stages of power settling, the large amount of excess power may be sufficient to overcome the upflow near the center of the rotor. If the sink rate reaches a higher rate, power will not be available to break this upflow and thus alter the vortex ring state of flow.

Normal tendency is for pilots to recover from a descent by application of collective pitch and power. If insufficient power is available for recovery, this action may aggravate power settling resulting in more turbulence and a higher rate of descent. Recovery can be accomplished by lowering collective pitch and increasing forward speed. Both of these methods of recovery require altitude to be successful.

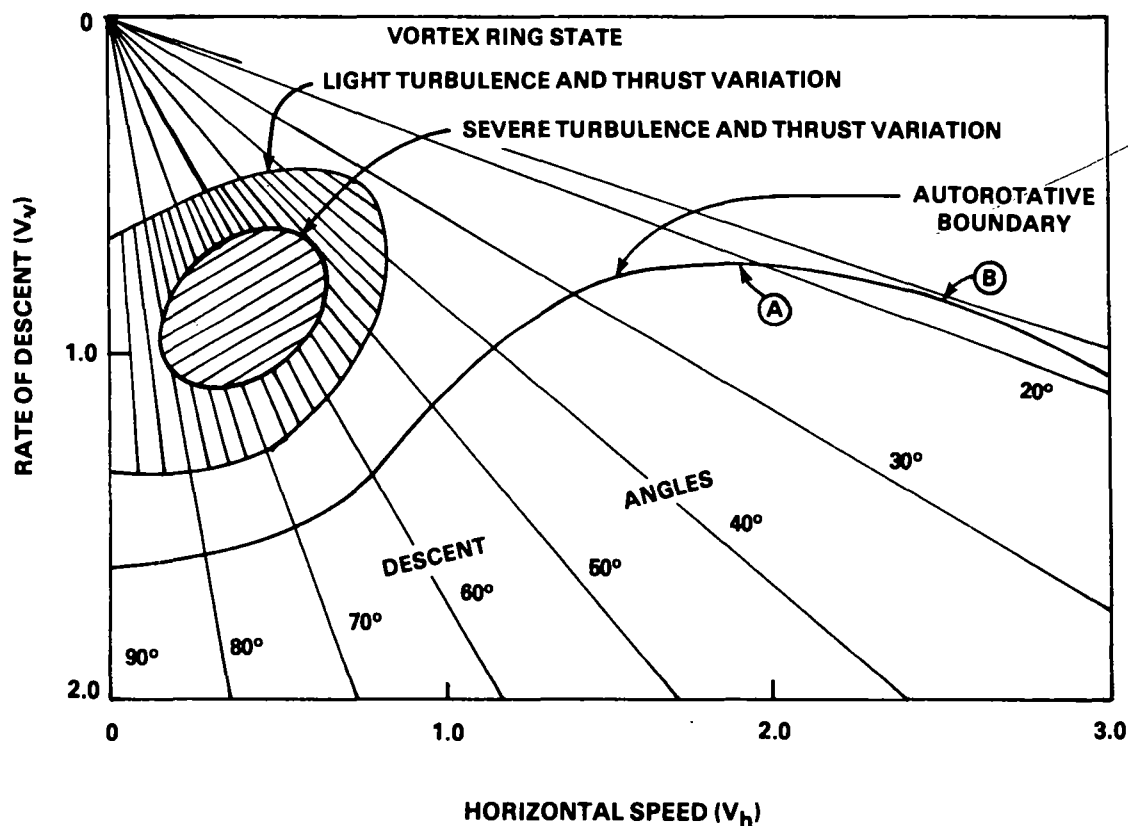


FIGURE 2-82. FLOW STATES IN DESCENDING FORWARD FLIGHT.

Certain helicopter designs are subject to *sympathetic* and *ground resonance*.

□ *Sympathetic resonance* is a harmonic beat between the main and tail rotor systems or other components or assemblies which might damage the helicopter. This type of resonance has been engineered out of most helicopters (e.g., by designing the main and tail gearboxes in odd decimal ratios). Thus, the beat of one component (assembly) cannot, under normal conditions, harmonize with the beat of another

component; and sympathetic resonance is not of immediate concern to the aviator. However, when resonance ranges are not designed out, the helicopter tachometer is appropriately marked; and the resonance range must be avoided (see applicable Operator's Manual).

□ *Ground resonance* may develop in helicopters having fully articulated rotor systems when a series of shocks cause the rotor blades in the system to become positioned in unbalanced displacement. If this oscillating condition is allowed to progress, it can be self-energizing and

extremely dangerous; and it usually results in structural failure. Ground resonance is most common to three-bladed helicopters having landing wheels. The rotor blades in a three-bladed helicopter are equally spaced (120°), but are constructed to allow some horizontal lead and lag action. Ground resonance occurs when the helicopter makes contact with the ground during landing or takeoff. When one wheel of the helicopter strikes the ground ahead of the other(s), a shock is transmitted through the fuselage to the rotor. Another shock is transmitted when the next wheel hits. The first shock from ground contact (A, fig 2-83) causes the blades straddling the contact point to jolt out of angular balance.

If repeated by the next contact (B, fig 2-83), a resonance is established which sets up a self-energizing oscillation of the fuselage. Unless immediate corrective action is taken, the oscillation severity increases rapidly and the helicopter may disintegrate.

- If rotor RPM is in the normal range, take off to a hover. A change of rotor RPM may also aid in breaking the oscillation.

- If rotor RPM is below the normal range, reduce power. Use of the rotor brake may also aid in breaking the oscillation.

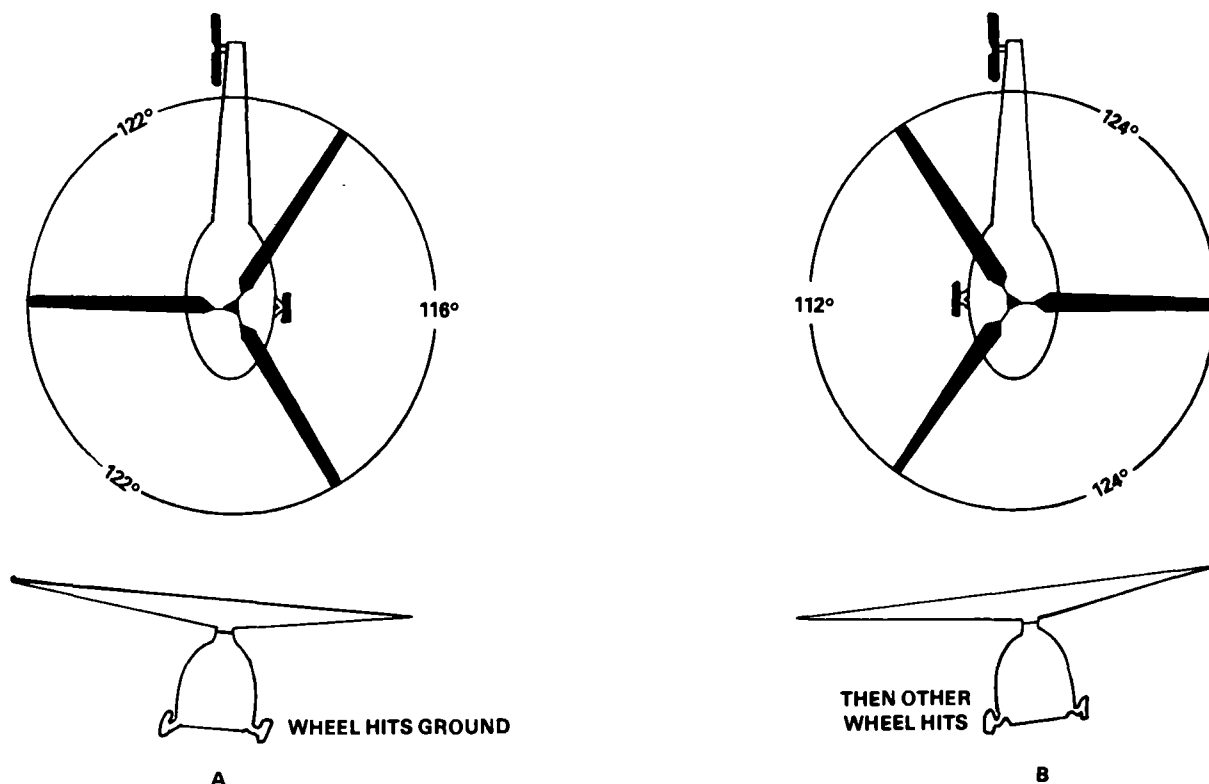


FIGURE 2-83. GROUND SHOCK CAUSING BLADE UNBALANCE.

AERODYNAMICS OF VERTICAL AUTOROTATION

During powered flight, the rotor drag is overcome with engine power. When the engine fails, or is deliberately disengaged from the rotor system, some other force must be used to sustain rotor RPM so controlled flight can be continued to the ground. This force is generated by adjusting the collective pitch to allow a controlled descent. Airflow during helicopter descent provides the energy to overcome blade drag and turn the rotor. When the helicopter is descending in this manner, it is said to be in a state of *autorotation*. In effect the pilot gives up altitude at a controlled rate in return for energy to turn the rotor at an RPM which provides aircraft control. Stated another way, the helicopter has potential energy by virtue of its position (altitude). As altitude decreases, potential energy is converted to kinetic energy and stored in the turning rotor. The pilot uses this kinetic energy to cushion the touchdown when near the ground:

Most autorotations are performed with forward speed. For simplicity, the following aerodynamic explanation is based on a vertical autorotative descent (no forward speed) in still air. Under these conditions, the forces that cause the blades to turn are similar for all blades regardless of their position in the plane of rotation. Dissymmetry of lift resulting from helicopter airspeed is therefore not a factor, but will be discussed later.

During vertical autorotation, the rotor disk is divided into three regions as illustrated in figure 2-84.

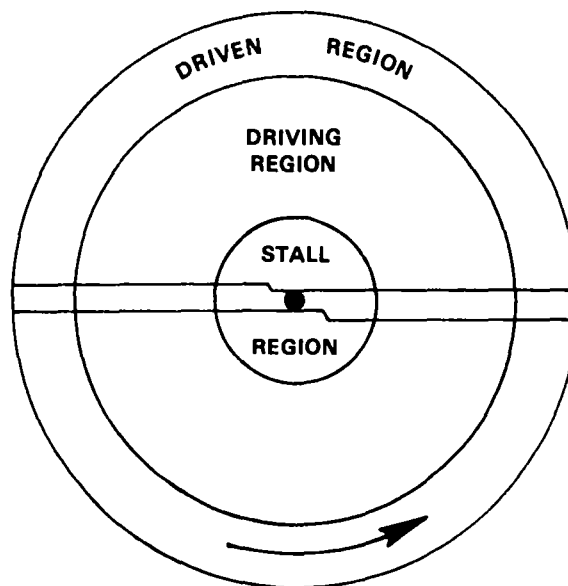


FIGURE 2-84. BLADE REGIONS IN
VERTICAL AUTOROTATION DESCENT.

□ The *driven region*, also called the *propeller region*, is nearest to the blade tips and normally consists of about 30 percent of the radius. The total aerodynamic force in this region is inclined slightly behind the rotating axis. This results in a drag force which tends to slow the rotation of the blade.

□ The *driving region*, or *autorotative region*, normally lies between about 25 to 70 percent of the blade radius. Total aerodynamic force in this region is inclined slightly forward of the axis of rotation. This inclination supplies thrust which tends to accelerate the rotation of the blade.

□ The *stall region* includes the inboard 25 percent of the blade radius. It operates above the stall angle of attack and causes drag which tends to slow the rotation of the blade.

Figure 2-85 shows three blade sections that illustrate force vectors in the driven region (A), a region of equilibrium (B), and the driving region (C). The force vectors are different in each region, because the rotational relative wind is slower near the blade root and increases continually toward the blade tip. When the inflow up through the rotor combines with rotational relative wind, it produces different combinations of aerodynamic force at every point along the blade.

In the driven region (A, fig 2-85), the total aerodynamic force acts behind the axis of rotation, resulting in an overall dragging force. This area produces lift; but it also opposes rotation and continually tends to decelerate the blade. The size of this region varies with blade pitch setting, rate of descent, and rotor RPM. When the pilot takes action to change autorotative RPM, blade pitch, or rate of descent, he is in effect changing the size of the driven region in relation to the other regions.

Between the driven region and the driving region is a point of equilibrium (B, fig 2-85). At this point on the blade, total aerodynamic force is aligned with the axis of rotation. Lift and drag are produced, but the total effect produces neither acceleration nor deceleration. Point D is also an area of equilibrium in regard to thrust and drag.

Area C, figure 2-85, is the driving region of the blade and produces the forces needed to turn the blades during autorotation. Total aerodynamic force in the driving region is inclined forward of the axis of rotation and produces a continual acceleration force. Driving region size varies with blade pitch setting, rate of descent and rotor RPM. The pilot controls the size of this region in relation to the driven and stall regions in order to adjust autorotative RPM. For example, if the collective pitch stick is raised, the pitch angle will increase in all regions. This causes the point of equilibrium (B, fig 2-85) to move toward the blade tip, decreasing the size of the driven region. The entire driving region also moves toward the blade tip. The stall region becomes larger and the total blade drag is increased, causing RPM decrease.

A constant rotor RPM is achieved by adjusting the collective pitch stick so blade acceleration forces from the driving region (C, fig 2-85) are balanced with the deceleration forces from the driven and stall regions (A, E, fig 2-85).

AERODYNAMICS OF AUTOROTATION IN FORWARD FLIGHT

Autorotative force in forward flight is produced in exactly the same manner as when the helicopter is descending vertically in still air. However, because forward speed changes the inflow of air up through the rotor disk, the driving region and stall region move toward the retreating side of the disk where angle of attack is larger (fig 2-86). Because of lower angles of attack on the advancing side blade, more of that blade falls in the driven region. On the

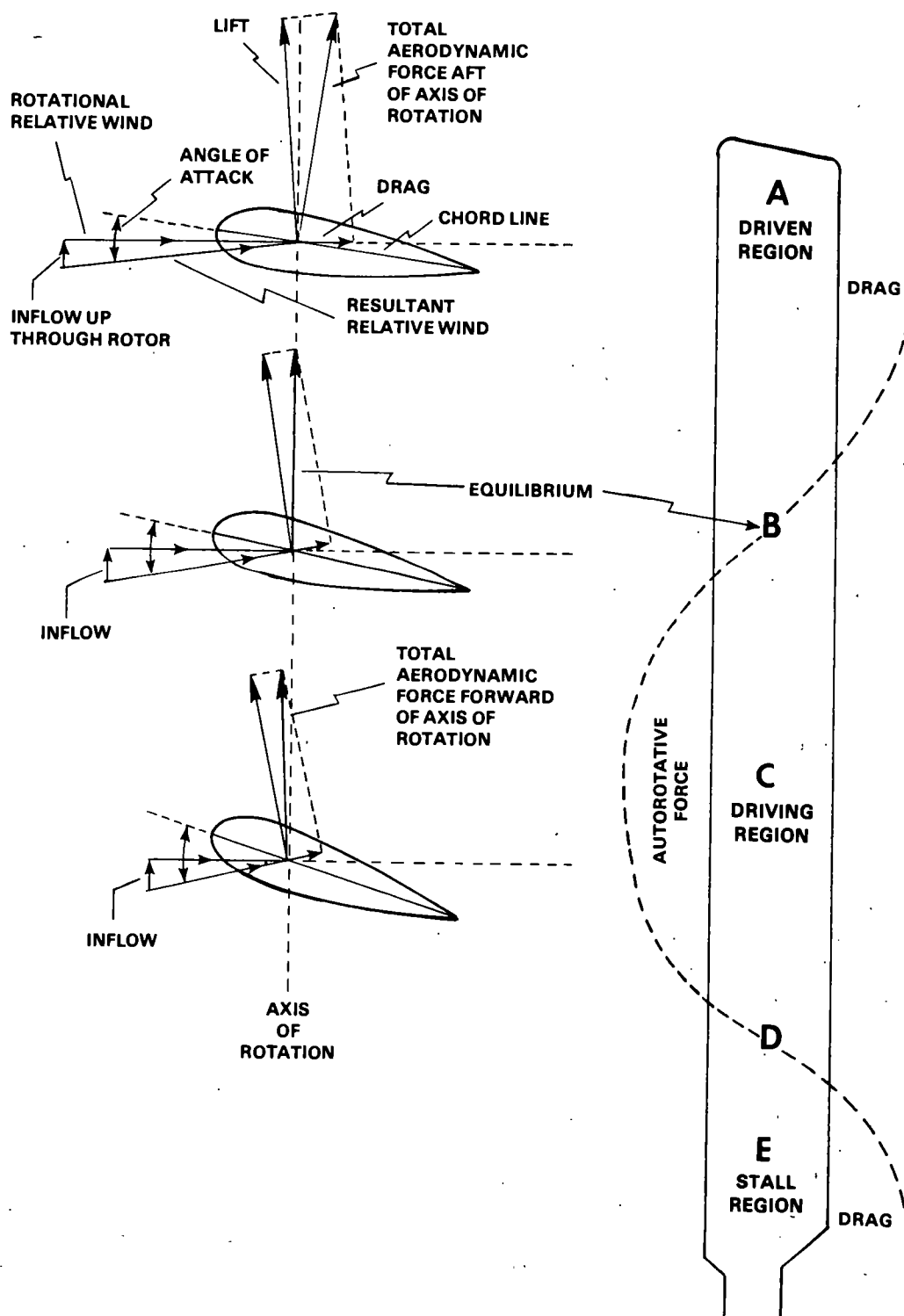


FIGURE 2-85. FORCE VECTORS IN VERTICAL AUTOROTATIVE DESCENT.

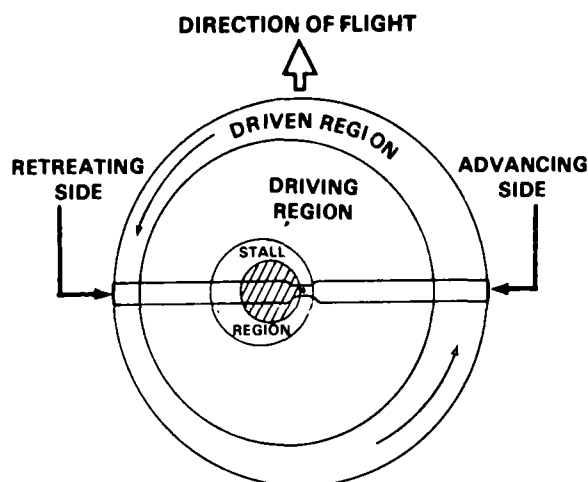


FIGURE 2-86. AUTOROTATIVE REGIONS IN FORWARD FLIGHT.

retreating side blade, more of the blade is in the stall region; and a small section near the root experiences a reversed flow. The size of the driven region on the retreating side is reduced.

Autorotations may be divided into three distinct phases: the *entry*, the *steady state descent*, and the *deceleration and touch-down*. Each of these phases is aerodynamically different than the others. The following discussion describes forces pertinent to each phase.

□ *Entry* into autorotation is performed following loss of engine power. Immediate indications of power loss are rotor RPM decay and an out-of-trim condition. Rate of RPM decay is most rapid when the helicopter is at high gross weight, high forward speed, or in high density altitude conditions. All of these conditions demand increased collective pitch and torque to maintain powered flight and so result in

rapid RPM decay when the engine stops. In most helicopters, it takes only seconds for the RPM decay to reach a minimum safe range. Pilots must react quickly and initiate a reduction in collective pitch that will prevent excessive RPM decay. A cyclic flare will help prevent excessive decay if the failure occurs at high speed. This technique varies with the model helicopter. Pilots should consult and follow the appropriate aircraft Operator's Manual.

● Figure 2-87 shows the airflow and force vectors for a blade in powered flight at high speed. Note that the lift and drag vectors are large and the total aerodynamic force is inclined well to the rear of the axis of rotation. If the engine stops when the helicopter is in this condition, rotor RPM decay is rapid. To prevent RPM decay, the pilot must promptly lower the collective pitch control to reduce drag and incline the total aerodynamic force vector forward so it is near the axis of rotation.

● Figure 2-88 shows the airflow and force vectors for a helicopter just after power loss. The collective pitch has been reduced, but the helicopter has not started to descend. Note that lift and drag are reduced and the total aerodynamic force vector is inclined further forward than it was in powered flight. As the helicopter begins to descend, the airflow changes. This causes the total aerodynamic force to incline further forward. It will reach an equilibrium that maintains a safe operating RPM. The pilot establishes a glide at the proper airspeed which is 50 to 75 knots, depending on the helicopter and its gross weight. Rotor RPM should be stabilized at autorotative RPM which is normally a few turns higher than normal operating RPM.

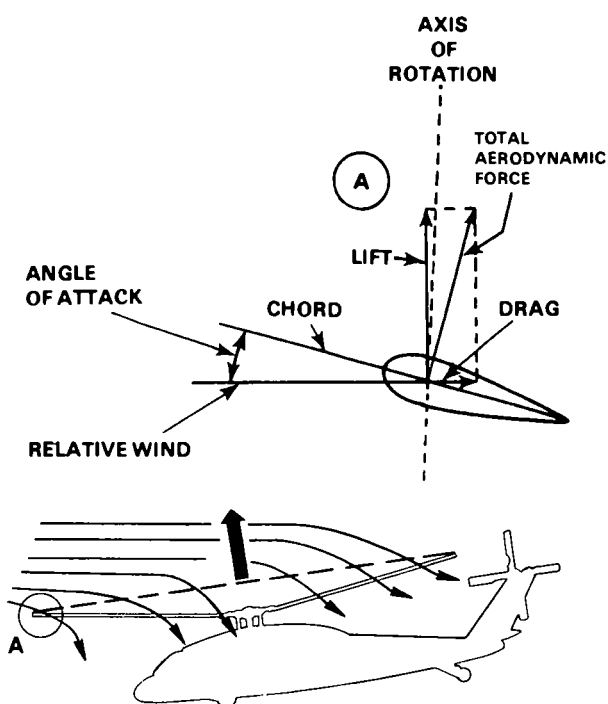


FIGURE 2-87. FORCE VECTORS IN LEVEL POWERED FLIGHT AT HIGH SPEED.

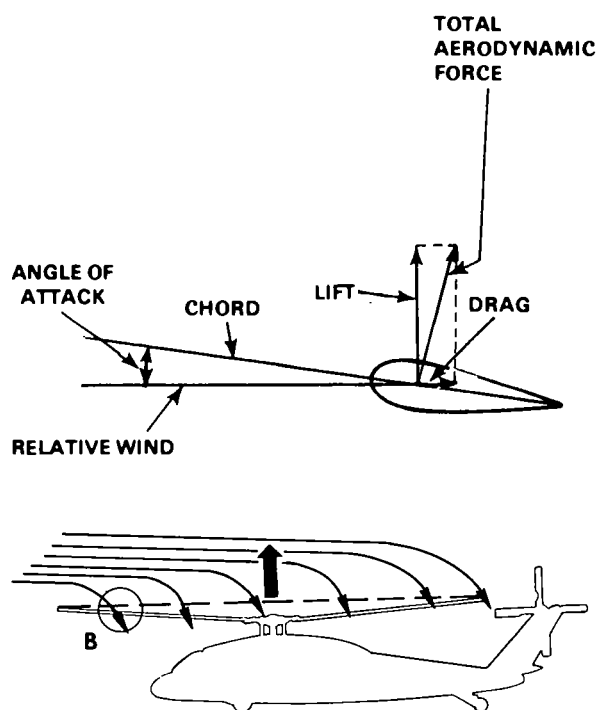


FIGURE 2-88. FORCE VECTORS AFTER POWER LOSS WITH REDUCED COLLECTIVE.

□ Figure 2-89 shows the helicopter in a *steady state descent*. Airflow is now upward through the rotor disk due to the descent. Changed airflow creates a larger angle of attack although blade pitch angle is the same as it was in figure 2-88 before the descent began. Total aerodynamic force is increased and inclined forward so equilibrium is established. Rate of descent and RPM are stabilized, and the helicopter is descending at a constant angle. Angle of descent is normally 17° to 20° , depending on airspeed, density altitude, wind, the model helicopter and other variables.

□ Figure 2-90 illustrates the aerodynamics of autorotative *deceleration*. To successfully perform an autorotative landing, the pilot must reduce airspeed and rate of descent just before touchdown. Both of

these actions can be partially accomplished by moving the cyclic control to the rear and changing the attitude of the rotor disk with relation to the relative wind (fig 2-90). The attitude change inclines the total force of the rotor disk to the rear and slows forward speed. It also increases angle of attack on all blades by changing the inflow of air. As a result, total rotor lifting force is increased and rate of descent is reduced. RPM also increases when the total aerodynamic force vector is lengthened (fig 2-90), thereby increasing blade kinetic energy available to cushion the touchdown. After forward speed is reduced to a safe landing speed, the helicopter is placed in a landing attitude as collective pitch is applied to cushion the touchdown. Specific values for RPM, airspeed, and technique are found in appropriate aircraft Operator's Manuals.

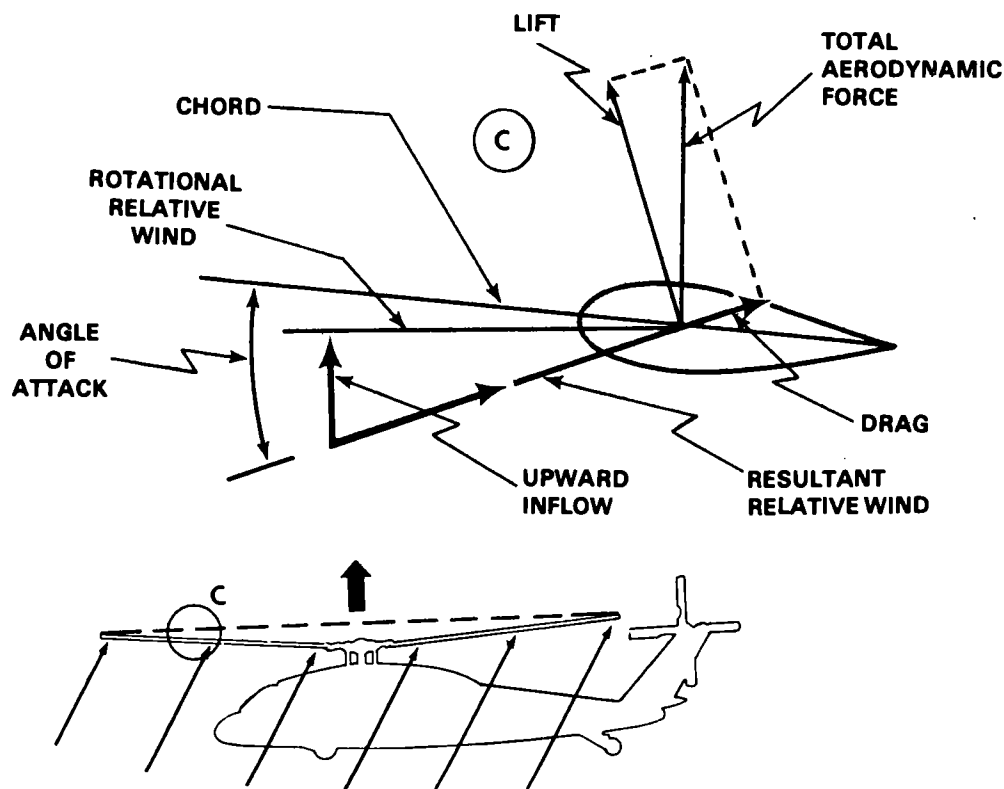


FIGURE 2-89. FORCE VECTORS IN AUTOROTATION STEADY STATE DESCENT.

GLIDE AND RATE OF DESCENT IN AUTOROTATION

Helicopter airspeed is probably the most significant factor affecting rate of descent in autorotation. Rate of descent is large at very low airspeeds; decreases to a minimum at some intermediate speed; then increases again at faster speed. Figure 2-82 shows the relationship between speed and rate of descent. Note that rate of descent is highest at zero horizontal speed. It decreases and reaches the minimum rate at point A, an intermediate horizontal speed.

Then rate of descent increases again and provides the shallowest possible flightpath angle at point B, where the degree angle line is tangent to the autorotative boundary line. This is the best horizontal speed for maximum glide distance.

Each type helicopter has specific airspeeds (given in the autorotation chart of the Operator's Manual) at which a poweroff glide will cover maximum distance. This airspeed is usually at, or slightly above, normal cruise airspeed. Also shown in these charts are airspeeds which will result in the slowest rate of descent. These airspeeds

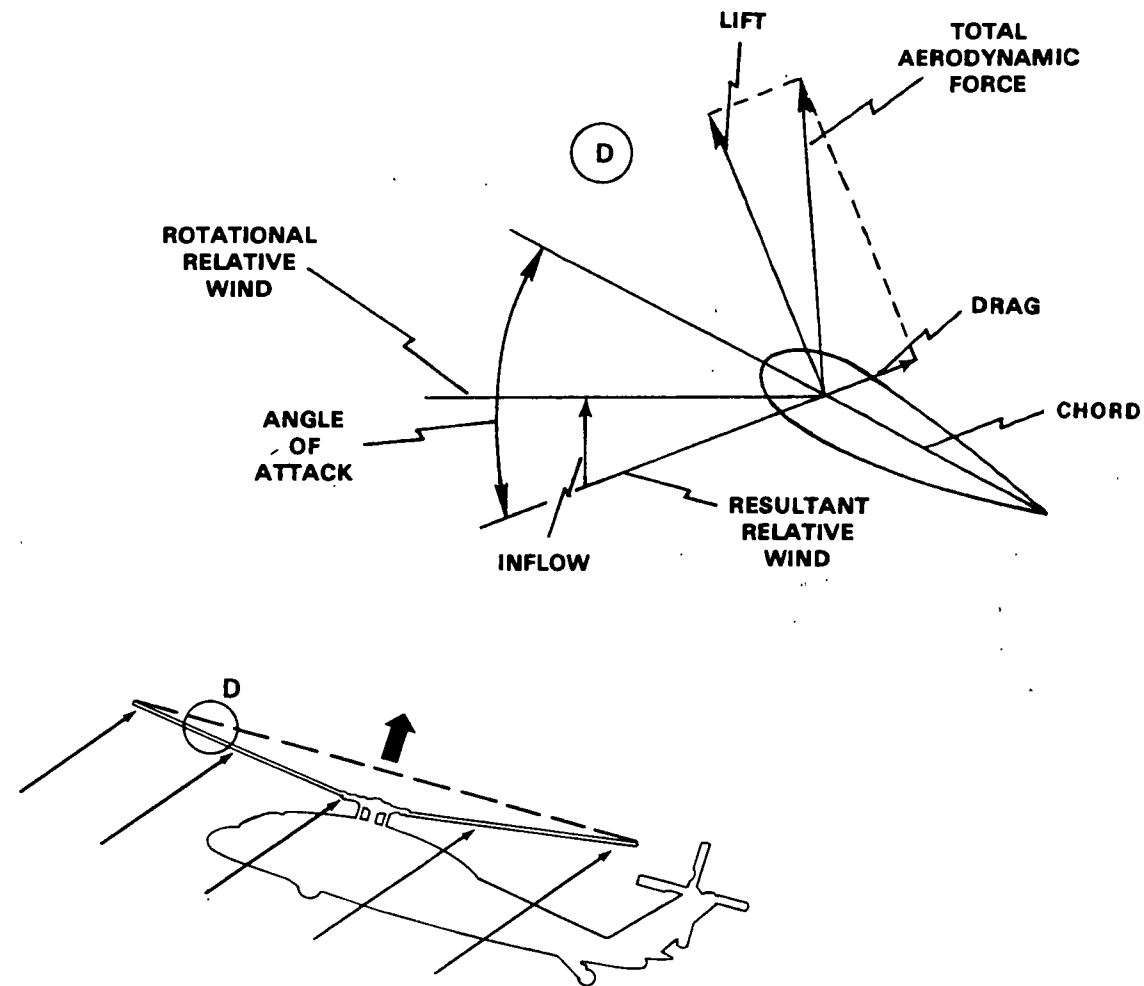
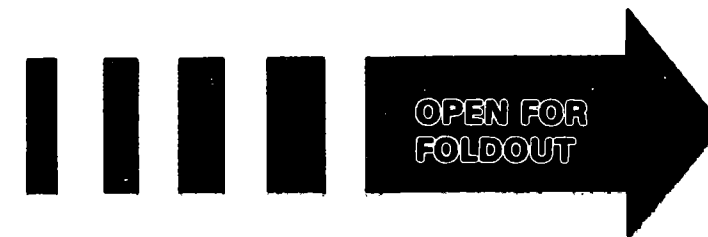


FIGURE 2-90. AUTOROTATIVE DECELERATION.

usually are at, or near, slow cruise airspeed.

Specific airspeeds for maximum distance or slowest rate of descent are established on the basis of standard density altitude with average weather and wind conditions and normal loading. When the helicopter is operated with excessive loads in high density altitude or strong, gusty wind

conditions, best performance is achieved from a slightly increased airspeed during the descent. For autorotation in light winds and low density altitude, best performance is achieved from a slight decrease in normal airspeed. Following this general procedure of fitting airspeed to existing conditions, an aviator can achieve approximately the same glide angle in any set of circumstances and estimate his touchdown point.



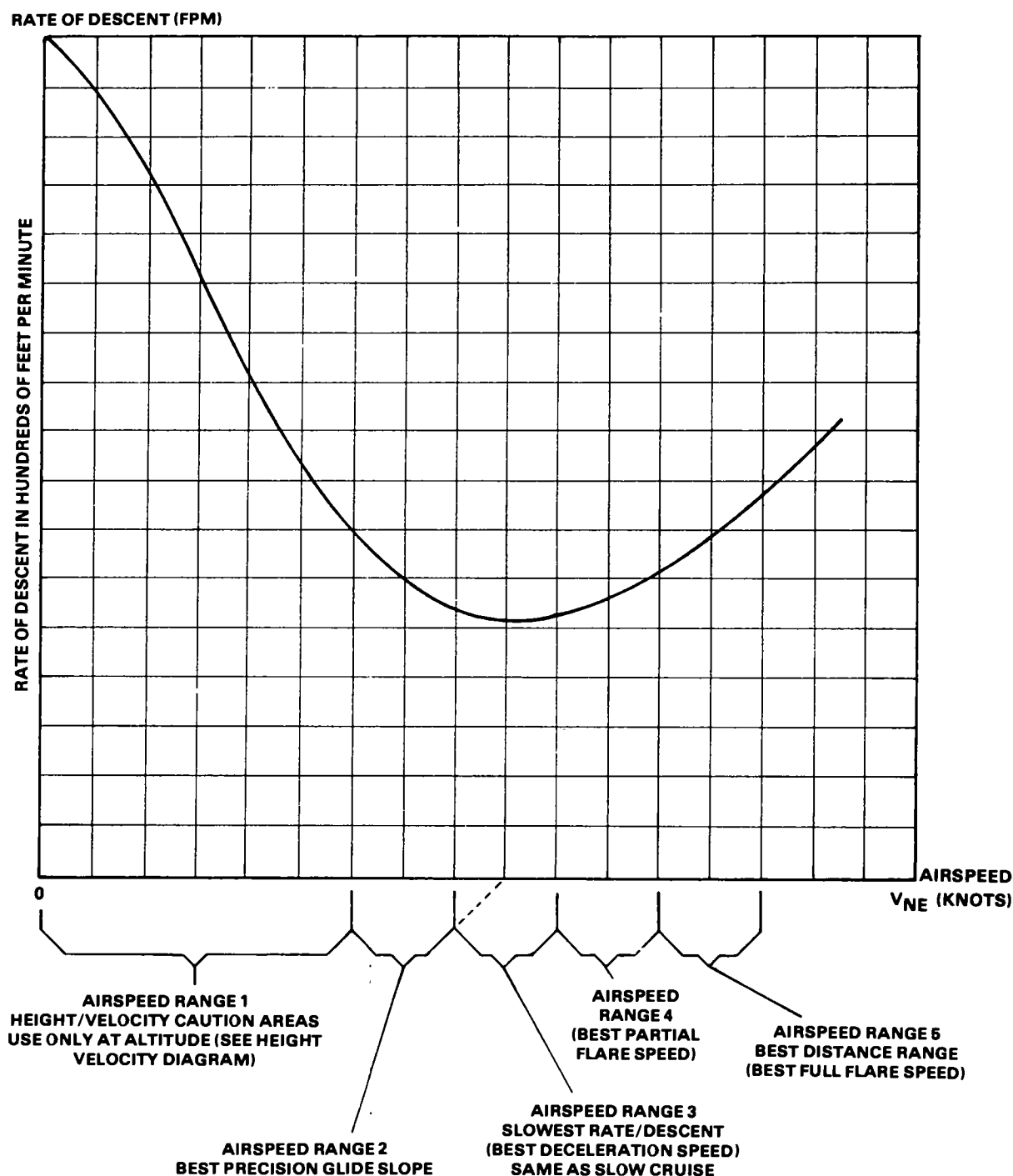


FIGURE 2-91. STEADY STATE AUTOROTATION RATE OF DESCENT (FPM) FOR VARIOUS AIRSPEEDS.

For example, the best glide ratio (maximum distance) for the average helicopter, in a no-wind condition, is about 4 feet of forward glide to 1 foot of descent. Ideal airspeed for minimum rate of descent is at slow cruise values and with a glide ratio of 3 feet forward to 1 foot of descent. Above and below this airspeed, the rate of descent rapidly increases.

A study of the autorotation chart in figure 2-91 shows typical rates of descent for the various airspeeds for steady state autorotation. This type of graph in an Operator's Manual would give the basic information required for introduction to precision autorotation. The normally acceptable autorotation airspeed ranges for the various models of helicopters for aviators having average skills vary from slightly less than slow cruise values to slightly higher than cruise values (ranges 2 through 5 of figures 2-91 and 2-92). In airspeeds of range 2 to midpoint range 3 of figure 2-92 note that a slight change of airspeed results in a large selection in rates of descent; therefore, this is the best precision airspeed glide slope. An aviator in a steady state autorotation in this airspeed range may advance or retreat the point of ground contact noticeably by increasing or decreasing the airspeed by as little as 5 knots. Airspeeds of less than range 2 yield increasingly high rates of descent.

Figure 2-92 shows eight example entry points for the entire forced landing and precision autorotation envelope. These entry points show positions on the front side, back side, and inside of the precision glide slope. Before considering each of these entry points in detail, some important general considerations to be remembered are as follows:

□ The best precision airspeed range as shown in figure 2-91 is between range 2 and range 3. When plotted in profile, this airspeed spread becomes the precision glide slope or the cone of precision.

□ The main effort in performing the precision autorotation at entry points 1, 2, 4, 5, and 6, is to intercept and stay inside the precision glide slope. The precision glide slope must be intercepted as soon as possible; then a steady state airspeed is established and tested, holding a slow cruise attitude.

□ The circle of action point (fig 2-92) is the circle of action or the point of collision (which is two or three helicopter lengths short of the touchdown), where (to the eye) the helicopter would hit the ground if collective pitch were not applied.

□ For recognition purposes, entry point 6 can be considered as the entry position for the familiar standard autorotation.

□ The precision autorotation flight envelope ends at 100 feet. A basic type termination can be made thereafter to a touchdown point (fig 2-92), provided the airspeed is within allowable tolerance of range 3 and the rate of descent is normal. See other terminations in figure 2-93.

□ For maneuver repeatability, exact attitudes must be used or noted throughout the autorotation. The center of attention is split between attitude and the circle of action point. All other references such as airspeed, rotor RPM, etc., are read in a running cross-check.

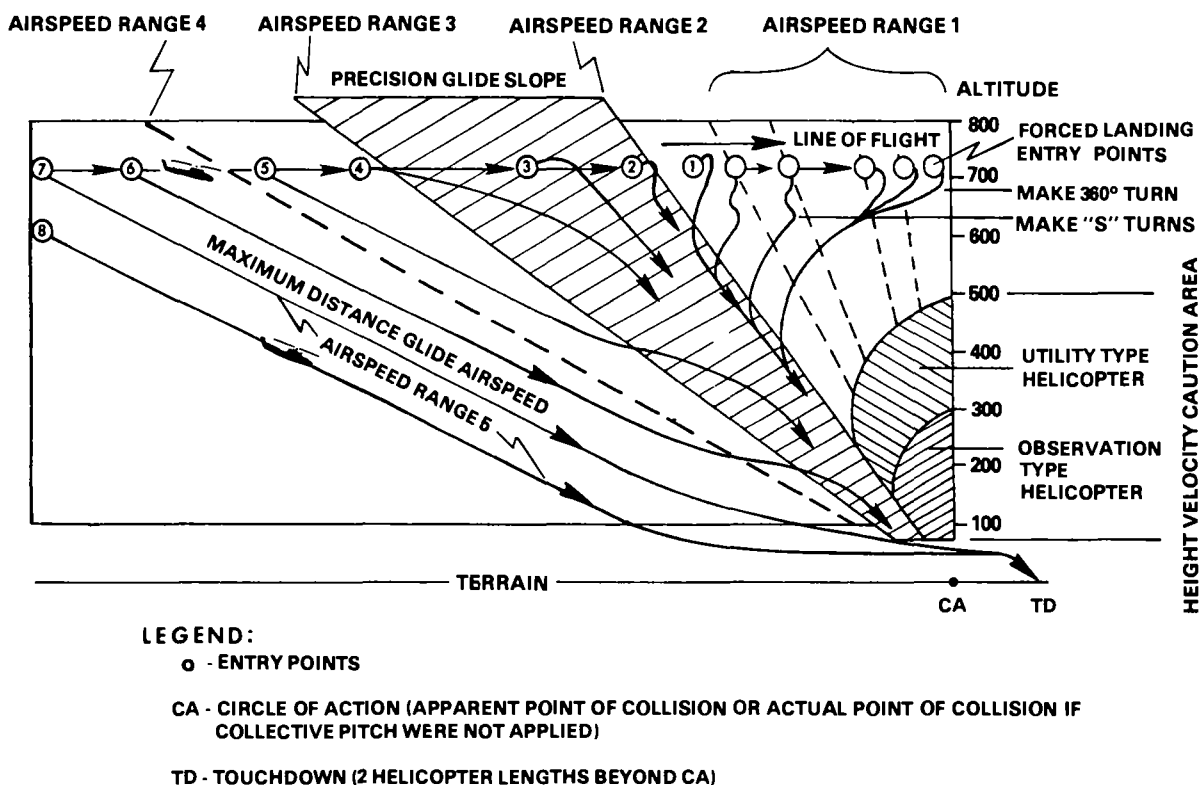


FIGURE 2-92. FORCE LANDING AUTOROTATION FLIGHT ENVELOPE FOR TYPICAL HELICOPTERS.

□ The airspeed values and restrictions of the height velocity diagram must be scaled up to comply with the performance charts of larger helicopters. Height velocity diagrams are based on a standard day at sea level, and the envelopes must be expanded in proportion to increasing density altitude (fig 2-94).

Procedures described under Entry Points No. 1, 2, and 3 that follow are for discussion only and should not be performed in training. Considerable risk is involved in performing these maneuvers. They are included so the pilot will have the knowledge and can attempt these type landings if required during an actual forward landing.

□ *Entry Point No. 1: (Not a training maneuver.)*

- In the area of entry point No. 1 (fig 2-92), the touchdown point appears to be almost vertical to the pilot.

- At cruise airspeed into the wind and at 700 feet above ground level (AGL) when the throttle is reduced, lower collective pitch, hold heading, and decelerate promptly for speed reduction climb—stopping all apparent groundspeed at the intended landing spot.

- Hold the nose high attitude until the airspeed goes through 15 knots, then slowly lower the attitude at a rate so as to establish a 0-knot reading and a slow cruise

or hovering attitude. (Optional, make "S" turns holding range 2 airspeed.)

- Settle vertically; a headwind will cause a slight rearward movement.

- When it appears that the helicopter is about to intercept the precision glide slope, lower attitude smoothly and progressively to a point slightly below the normal takeoff acceleration attitude.

- *When the airspeed reaches between range 2 and range 3, rotate to a slow cruise attitude.

- Watch the circle of action point for evidence of overshooting or undershooting.

- If undershooting, lower attitude to gain 5 knots; then return attitude to slow cruise (for further reading of the circle of action point).

- *If overshooting, raise attitude to lose 5 knots; then return attitude to slow cruise (for further reading of the circle of action point).

- At 100 feet, if airspeed is within allowable tolerance of range 3, terminate as in a standard autorotation for a landing at the touchdown point.

- At 100 feet, if airspeed is range 2, hold slow cruise attitude to approximately 50 feet; then rotate to the normal deceleration attitude.

*In reading the precision line of descent, observation of the circle of action point is reliable only when the attitude is at slow cruise and when a steady state autorotation is in progress (no deceleration, no acceleration).

- Touchdown on TD point as in basic autorotation touchdown.

☐ *Entry Point No. 2:* (Not a training maneuver.)

- In the area of entry point No. 2 (fig 2-92), the student estimates that he is almost beyond the precision glide slope.

- At cruise airspeed and at 700 feet AGL, when the throttle is reduced, lower collective pitch, hold heading, and decelerate promptly for a speed reduction climb—stopping all apparent groundspeed at the intended landing spot.

- As the apparent groundspeed reaches 0 knots, lower attitude to the slow cruise attitude. (The airspeed will now be equal to, or near, the wind velocity.)

- Settle vertically and continue as indicated in exercise "Entry Point No. 1" to remain within the precision glide slope.

☐ *Entry Point No. 3:* (Not a training maneuver.)

- In the area of entry point No. 3 (fig 2-92), the student estimates that he is well into the precision glide slope.

- At cruise airspeed and at 700 feet AGL, when the throttle is reduced, lower collective pitch, hold heading, and make speed reduction climb.

- As the airspeed approaches between range 2 and range 3 (depending upon the headwind effect on groundspeed), lower attitude to the slow cruise attitude for a steady state autorotation. Then proceed as

indicated in exercise "Entry Point No. 1" to remain within the precision glide slope.

☐ *Entry Point No. 4:*

- In the area of entry point No. 4 (fig 2-92), the student estimates that he is just short of the precision glide slope.

- At cruise airspeed and at 700 feet AGL, when the throttle is reduced, lower collective pitch, hold heading, and decelerate smoothly. This will cause a lifting up to the precision glide slope.

- As the airspeed approaches between range 2 and range 3 (depending upon the headwind effect on groundspeed), lower attitude to the slow cruise attitude for a steady state autorotation. Then proceed as indicated in exercise "Entry Point No. 1," to remain within the precision glide slope.

NOTE: Exercise No. 4 is the example to use when demonstrating an ideal precision autorotation.

☐ *Entry Point No. 5:*

- In the area of entry point No. 5 (fig 2-92), the student estimates that he is well short of the precision glide slope.

- At cruise airspeed and at 700 feet when the throttle is reduced, lower collective pitch, hold heading, cruise attitude, and rotor RPM for best distance. (Hold crab, rather than slip, for best distance.)

- When it appears that the precision glide slope is just ahead, do a partial deceleration. This will cause lifting up to the precision glide slope.

- As airspeed approaches between range 2 and range 3, rotate attitude to slow cruise for a steady state autorotation and proceed as indicated in exercise "Entry Point No. 1," to remain within the precision glide slope.

☐ *Entry Point No. 6:*

- In the area of entry point No. 6 (fig 2-92), the student estimates that he is almost too far back for interception of the precision glide slope.

- He proceeds as in entry point No. 5 with possible interception of the precision glide slope further down the line of descent. However, he may decide to proceed as for entry point No. 7.

☐ *Entry Point No. 7:*

- In the area of entry point No. 7 (fig 2-92), the student estimates that he cannot intercept the precision glide slope.

- At cruise airspeed and at 700 feet AGL when the throttle is cut, lower collective pitch, and hold heading and cruise attitude for best distance.

- The line of descent appears to be a spot well short of the touchdown point.

- At approximately 200 feet, begin a smooth lifting partial deceleration, converting speed to lift. This will change the line of descent toward the touchdown point.

- By regulating the rate and amount of deceleration from 200 feet on, a basic type termination can be made at the touchdown point.

☐ *Entry Point No. 8:*

- This exercise is identical to the exercise for entry point No. 7 except that the entry is set up farther away from the precision glide slope than it was at No. 7.

- The line of descent appears to be to a point 100 feet (or more) short of the normal circle of action point.

- Hold best distance attitude, rotor RPM, and pedal trim. Upon reaching 40 to 60 feet altitude, execute a full deceleration which is regulated in rate and amount of attitude rotation, so as to arrive at the touchdown point at the end of the deceleration.

- Allow the helicopter to settle to 15 to 20 feet; apply initial collective pitch; rotate attitude to level landing attitude; and apply a firm positive collective pitch in the amount and at a rate necessary to cushion the landing.

THAT LAST 100 FEET

For purposes of clarity, assume that the autorotation ends at 100 feet and that the power-off landing procedure begins there. The accepted method of executing a power-off landing for rotary-wing aircraft is to obtain a smooth tradeoff of airspeed for lift during the last 100 feet. Ideally, beginning at 100 feet, airspeed is converted to additional lift by deceleration. The deceleration is so timed and applied that the rate of descent and the forward speed are reduced just before touchdown to the slowest rates possible for the existing conditions.

☐ *Potential energy available for power-off landing.* At 100 feet, the pilot must begin spending stored flight energies; i.e., the forward velocity of the helicopter and, just before touchdown, the rotational energy of the main rotor. At 100 feet, he can predict with accuracy the amount of potential energy (deceleration or cyclic lifting power) available for the power-off landing. He can also predict the effectiveness of applying collective pitch to cushion the touchdown.

☐ *Reducing the rate of descent and slowing the groundspeed.* All the heavy aerodynamic work of reducing the rate of descent and slowing the groundspeed should be a result of the pilot's effecting some form of deceleration, down to approximately 15 feet. Thereafter, his use of collective pitch further slows (at times, delays) the descent and then cushions the touchdown. See figure 2-93 for predictable conditions for the power-off landing.

☐ *Terms and definitions.* The following terms and definitions should be understood for the discussion of power-off landings in succeeding paragraphs.

- *Attitude Rotation*—A preplanned or scheduled change of aircraft attitude at some specific point in a maneuver sequence.

- *Deceleration*—A tradeoff of airspeed for lift while holding or maintaining a relatively continuous line of descent.

- *Partial Deceleration*—A tradeoff of airspeed for lift which results in a moderate change to the line of flight.

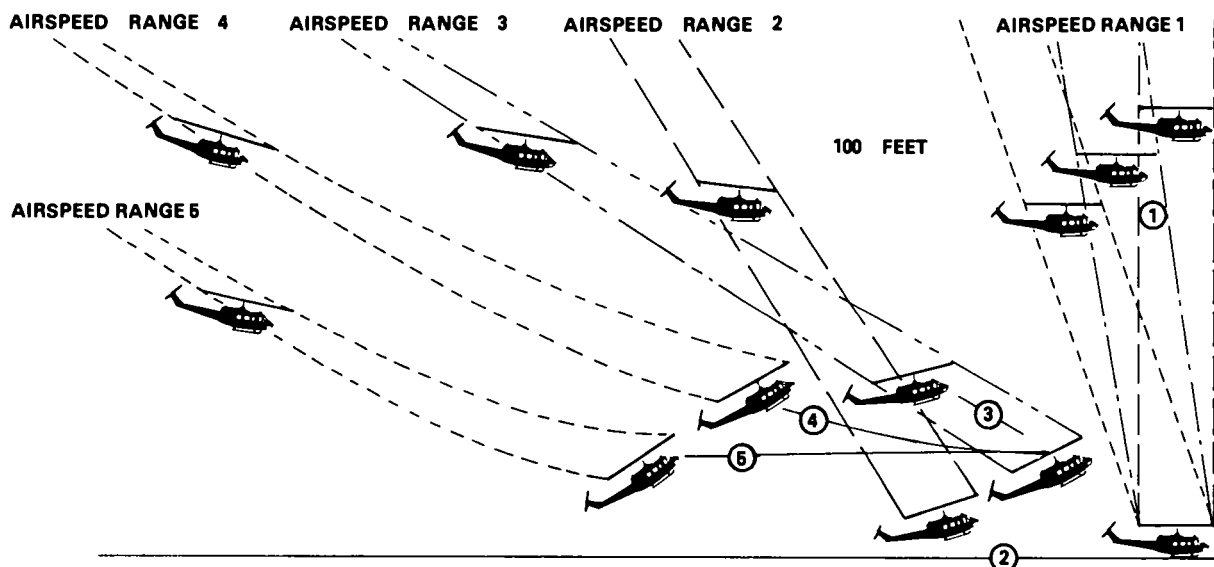


FIGURE 2-93. THAT LAST 100 FEET.

● **Full Deceleration**—A tradeoff of airspeed for lift which results in a substantial change to the line of flight. In autorotation at the appropriate altitude, the descending line of flight is changed by converting airspeed to lift, so as to parallel the ground for some distance.

NOTE: The terms deceleration, partial deceleration, and full deceleration do not apply to the attitude rotation per se, but to the change in lift and/or the change in the line of flight which results from the altitude rotation.

□ **Conditions.** Figure 2-93 shows the airspeed conditions at 100 feet and the following paragraphs describe the landing sequences resulting from those airspeed conditions.

● **Condition 5 (airspeed range 5, fig 2-93).** Condition 5 exists at 100 feet with airspeed range 5 (best distance-gliding

airspeed, see appropriate aircraft Operator's Manual). In condition 5, the helicopter is descending on a very narrow rotor profile to the line of descent. The helicopter is then encountering a large volume of air per second. This can produce exceptional lifting forces when the attitude is rotated smoothly and progressively and the full rotor diameter profile is presented to (or against) the line of descending flight. This attitude rotation is usually accomplished at 30 to 60 feet, depending on the aircraft.

The added lift generated by the full deceleration is so great that the descent will be stopped and the line of flight will parallel the ground for some distance. As the deceleration ends, with the density-altitude, wind, or gross weight favorable, the helicopter settles gently to a point where the pilot applies initial pitch. This is followed by the pilot's final application of collective pitch for a soft touchdown and a near zero ground run. All of this is predictable at 100 feet.

• *Condition 4 (airspeed range 4, fig 2-93).* Condition 4 exists at 100 feet, with airspeed range 4, in which the helicopter is descending on a narrow rotor profile to the line of descent. A smooth and progressive attitude change (deceleration) which presents a full rotor diameter profile to (or against) the line of descent will alter the line of descent and add lift. When properly timed, this added lift will greatly reduce the rate of descent and forward speed prior to the initial collective pitch application. The deceleration may also be used to increase rotor RPM prior to collective pitch application. All of this is predictable at 100 feet.

NOTE: The full or partial deceleration termination is necessary for a zero ground run. The full or partial deceleration is mandatory for helicopters having low rotor inertia with light unweighted blades and/or poor collective pitch effectiveness at termination.

• *Condition 3 (airspeed range 3, fig 2-93).* Condition 3 exists at 100 feet, with airspeed range 3, in which the helicopter is descending on slightly less than a full rotor diameter profile to the line of descent; translational lift is near maximum effect and the rate of descent is minimum. The pilot should know that a smooth and progressive rotation of attitude which presents a full rotor diameter profile to (or against) the line of descent will result in an effective deceleration.

This deceleration, while not noticeably changing the line of descent, will reduce the rate of descent and the forward speed to a

point where collective pitch energy will be quite effective. When the deceleration is timed correctly, the descent is often stopped completely when initial pitch is applied by the pilot. This still leaves adequate pitch to delay and then cushion the touchdown (when wind, density, altitude, or weight are favorable) resulting in a relatively short ground run. All of this is predictable at 100 feet.

• *Condition 2 (airspeed range 2, fig 2-93).* Condition 2 exists at 100 feet, with airspeed range 2, when the helicopter is descending on nearly a full rotor diameter profile. The pilot knows or should know that nothing will be gained by an attitude rotation; that he should hold a steady attitude to maintain the speed, at least down to 50 feet; and that, of the five conditions, condition 2 will give the longest ground run. Therefore, at about 50 feet, he should begin a progressive attitude change until a slight rearward tilt of the rotor occurs just prior to his application of collective pitch. The attitude change will not supply additional lift, but it will add a rearward component of lift during his pitch application. This will help slow and shorten the ground run.

It is predictable that, having no effective deceleration lift in progress (during the last 100 feet), the application of collective pitch alone will not provide sufficient lifting and braking action to have appreciable effect in delaying the touchdown and slowing the ground run. The ground run will be approximately three to four lengths. All of this is predictable at 100 feet.

The hidden danger in condition 2 lies in the frequency of occurrence of this condition. Another consideration is that condi-

tion 2 falls on the borderline of the height/velocity diagram. Often a wind gradient and/or high density altitude condition can then cause an increase in the rate of descent, thus increasing the lift demands on the collective pitch application. The resulting accident summary usually states that the damage was caused by a late and insufficient application of collective pitch. Actually, the error occurred earlier—at 100 feet. It was due to a lack of knowledge, cross-check, projection, and prediction. When condition 2 is performed knowledgeably, with normal atmospheric and gross weights, it is considered a SAFE operation.

• *Condition 1 (airspeed range 1, fig 2-93).* Condition 1 falls in the restricted areas of the height/velocity diagram. It exists at 100 feet, with airspeed range 1, when the helicopter is descending on a full rotor diameter profile to the line of descent. There is a high sink rate; no deceleration lift is possible. Due to a wind gradient, gusts, or wind shift, this condition may suddenly occur in the last 100 feet of descent. The entire rate of descent must then be stopped by the application of collective pitch alone. Usually the lift produced is insufficient for safe landings. Condition 1 may also cause obvious or hidden damage to the helicopter due to hard landings. Such damage might be acceptable for an actual engine failure, but it is never acceptable for normal training practice and a termination with power is necessary. All of this is predictable at 100 feet.

HEIGHT/VELOCITY DIAGRAM

A typical height/velocity diagram or “dead man’s curve” is shown in A, figure 2-94. The caution areas carry the warning “Avoid continuous operations—engine failure while operating within these caution areas is likely to result in damage to the helicopter.”

Caution area (A) of diagram A in figure 2-94 is computed from engineering data, with the following factors included:

□ Rate of descent required to drive the rotor in autorotation, for each 10-knot increment of airspeed (from 0 through red line or top speed) for the specific helicopter configuration. See diagram B, figure 2-94.

□ Rotor inertia characteristics or the rotor RPM decay rate, from the moment of engine failure or until engine failure cues become available to the pilot. The pilot reaction time must be added after the cues become available. It is also based on the rotor RPM decay rate experienced while sufficient vertical descent is achieved to drive the rotor.

□ Translational lift values and sink rates for each height/velocity condition, with the resulting rotor RPM and “pitch pull” energy then available for cushioning ground impact.

□ Designed stress limitations of the landing gear and “hard landing” damage-risk to other components.

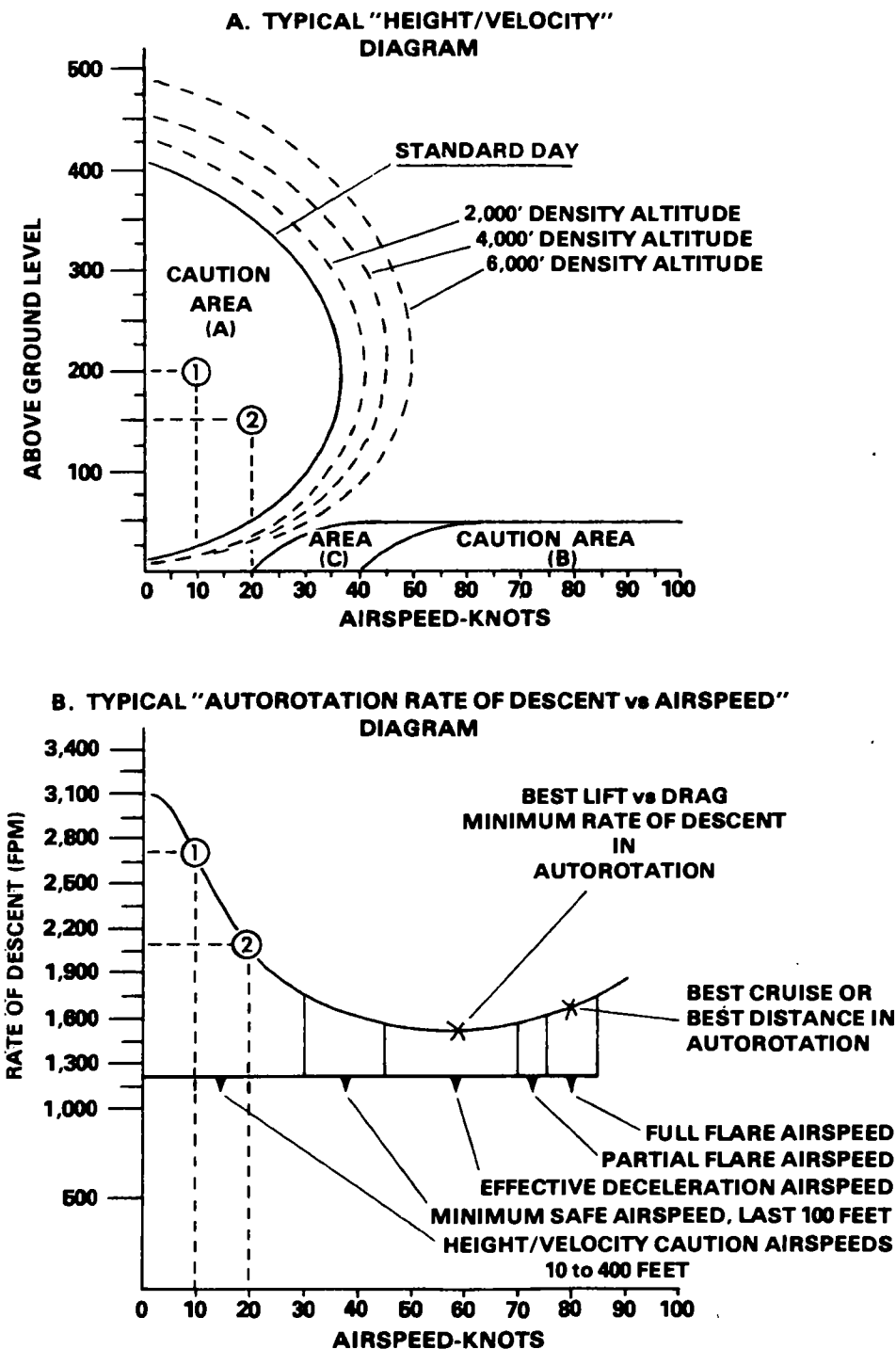
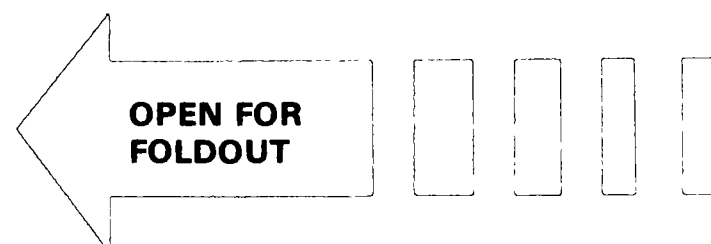


FIGURE 2-94. HEIGHT/VELOCITY DIAGRAM.

The combinations of altitude and air-speed which define the avoid areas of the height/velocity diagram are peculiar to each type of helicopter. They are dependent upon gross weight, pressure altitude, ambient temperature, velocity, engine power available, number of engines operating, and rotor speed. Typically, data in the aircraft's flight manual is presented graphically for sea level, standard temperature conditions at design gross weight. Scaling factors for other conditions may be noted in the text and should be observed.

The diagrams are plotted for a "steady state" constant airspeed and constant altitude; therefore, they do not apply to climbing flight. Engine failure occurring while climbing through any of the height/velocity combinations will usually result in damage to the helicopter. During a climb, the helicopter is operating at higher power settings and blade angles of attack. An engine failure will cause rapid rotor RPM decay because the helicopter must stop going upward, then begin and reach its descent in order to drive the rotor, stabilize the RPM; then increase the RPM to its normal range. The rate of descent must reach a value that is normal for the airspeed at the moment. Since altitude is insufficient for this sequence, the pilot ends up with the helicopter having decaying RPM, increasing sink rate, no deceleration lift, little translational lift, and little response to his application of collective pitch to cushion ground impact.

Operations in the caution area (A) of diagram A, figure 2-94, are much less dangerous during descending flight through any included height/velocity



combination, provided a landing site is available.

Caution area (B) of diagram A, figure 2-94, warns against continuous operations in certain low altitude/airspeed/terrain combinations. These restrictions are based upon:

[1] Pilot recognition time of engine failure cues.

[2] Time required to rotate from nose-low forward mode to a slight or moderate nose-high attitude.

[3] Altitude loss during [1] and [2] above, and groundspeed remaining as tail wheel/skid/guard/cone hits the ground or other obstacles.

NOTE: The similarity between [1], [2], and [3] above and the usual "low-level autorotation," as practiced to a runway, is almost nonexistent. The solution is for pilots to completely avoid operations in area "B" unless dictated by the tactical mission.

Area (C) of diagram A, figure 2-94, can be used over open level terrain or runways where obstacle evasion or direction change is not required and a short ground run is possible. This condition is similar to the usual practice low-level autorotation.

At slow airspeeds with an available landing site (as a general rule), the aviator should allow 300 feet for small helicopters and 500 to 600 feet for larger helicopters to set up a steady state autorotation and complete a reasonably safe landing.

An engine failure (A, fig 2-94) at 10 knots, 200 feet, requires 2,700 fpm rate of descent (B, fig 2-94) to drive the rotor at normal RPM.

An engine failure at 20 knots (A, fig 2-94), 150 feet, requires 2,100 fpm rate of descent (B, fig 2-94) to drive the rotor at normal RPM.

The rates of descent in examples (1) and (2) of diagram B, figure 2-94, will not be attained; therefore, rotor RPM will decay. No deceleration lift is possible to slow the rate of descent, and rotor inertia (RPM) will be low for the collective pitch application and touchdown. These combined effects will increase the possibility of a hard landing and structural damage to the helicopter.

Aviators must complete a wide variety of missions, portions of which include elements of risk. They should not operate in the caution areas of height/velocity diagram unless training or the tactical mission requires it. During terrain flight, aircraft may have to operate in the avoid areas of the height/velocity diagram. As a result, aviators should have a knowledge of the aircraft's height/velocity avoid areas and emergency procedures pertaining thereto.

CHAPTER 3

HELICOPTER FLIGHT TECHNIQUES

KNOWLEDGE, PLANNING AND PREDICTION

Basic flying techniques described in this chapter are generally applicable to all aircraft. The attitude flying concept introduced and enlarged during primary flight training promotes learning and establishes sound habit patterns. It provides for easy transition into larger, more complex aircraft and promotes smooth progression through instrument flight training and into

operational status in an aviation unit. The mechanics and techniques of flight, correctly learned in early training, produce aviators who are highly standardized. New aviators should be encouraged to study and use the basic concepts of attitude control flying and later attitude instrument flying. They should be encouraged to develop a working knowledge of how the aircraft components and vital systems function. With these knowledges and skills, aviators can adjust their flight performance to the requirements of future flight assignments.

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Aviator performance is built upon adequate knowledge, thorough *planning*, and the ability to project or *predict* what the aircraft will do. Coordination, feel, and control touch are also important factors, but they are secondary to the first three. Subject matter for aviation training, according to these principles, is listed below. Emphasis should be on the subject areas in the order listed.

☐ Knowledge of aerodynamics, physics, and mechanics of flight.

☐ Specific knowledge of the systems, components, controls, and structures of the helicopter being used.

☐ Knowledge of the methods and rules of *attitude flying* which are similar to the rules of attitude instrument flying in FM 1-5.

☐ Specific knowledge of the breakdown of attitudes and cross-checks for each maneuver; and development in dividing attention and cross-checking outward from a specific center of attention for each segment of a maneuver.

☐ Development of smooth and coordinated physical application of control; and the ability to hold attitudes and power settings or to change attitude and power as necessary to perform a maneuver.

Physical application of the controls is probably less important in the initial stages of training than the other four subject areas listed above. Physical skill is developed most rapidly after the aviator has mastered the first four subject areas. Aviators must learn *what to do* before they can develop the physical skills to perform a maneuver.

Descriptions of specific flight maneuvers for each Army aircraft are found in the appropriate Aircrew Training Manual and Operator's Manual.

ATTITUDE FLYING

Aircraft attitude is the position of the aircraft in relation to the horizon. Attitude is controlled about three imaginary axes: the *longitudinal axis*, the *lateral axis*, and the *vertical axis* (fig 3-1). When an aircraft banks (or rolls), it changes attitude about the longitudinal axis. Attitude change about the lateral axis is called *pitch*, and refers to raising or lowering the aircraft nose in relation to the horizon. Yaw (turning right or left) is attitude change about the vertical axis. During flight it is possible for an aircraft to change attitude about only one of these axes at a time. Frequently, however, attitude change will include movement about all three axes simultaneously.

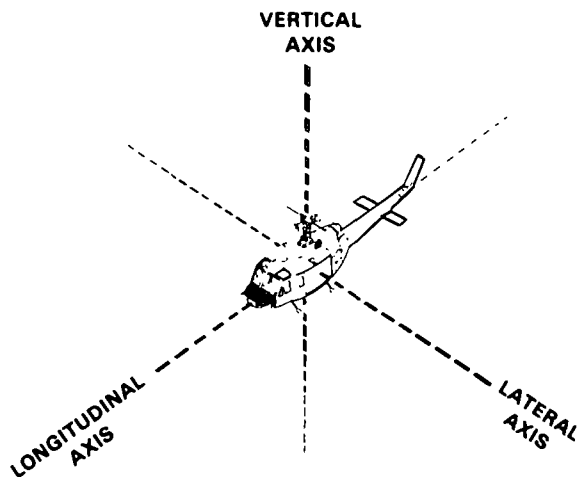


FIGURE 3-1. AXES ABOUT WHICH AIRCRAFT ATTITUDE IS CONTROLLED.

The attitude of the aircraft in relation to the horizon and the power applied are the only two elements of control in all aircraft. Proper use of these two elements of control will produce any desired maneuver within

the capability of the aircraft. Therefore, all maneuvers *must* be based solidly upon attitude and power control references.

Aircraft attitude and power are modified by the pilot in two ways; one, the time of application of an attitude or power change, and two, the rate of change of an attitude or power adjustment.

✓ Keeping the basic control elements and modifiers in mind, the aviator cross-checks for a running awareness of what the aircraft is doing at the moment. Using knowledge gained from experience, the aviator can project what the aircraft is going to do based on the power setting and attitude that is being maintained. Attitude and power changes are smoothly applied to cause the aircraft to perform the desired maneuver. The result is attitude flying.

ATTITUDE CONTROL AND AIRSPEED

Airspeed is controlled by adjusting pitch attitude about the lateral axis of the aircraft. To hold a desired airspeed, or make properly controlled changes of airspeed, the aviator must learn the aircraft pitch attitudes that will result in acceleration, deceleration, hover, and the desired cruising airspeeds.

For a given power setting, there is a pitch attitude and airspeed that will maintain altitude. If power is constant, an

increase in airspeed (resulting from a change of pitch attitude) will cause loss of altitude. Conversely, a reduction of airspeed with power constant will usually cause a gain of altitude.

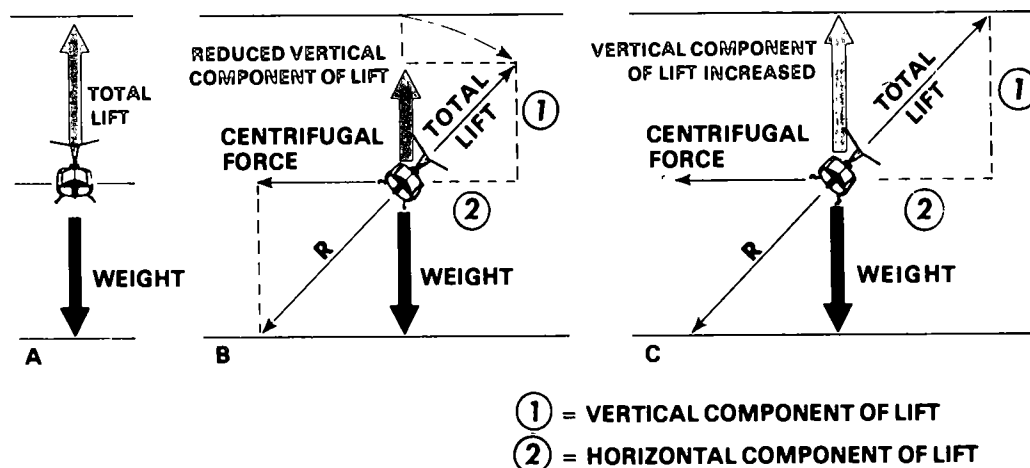
If power is increased while pitch attitude is held constant, a constant airspeed and climb will result. If the power setting is decreased while pitch attitude is held constant, airspeed will remain constant and a descent will result.

ATTITUDE CONTROL AND COORDINATED TURNS

During coordinated flight, turns are a result of bank attitude control about the longitudinal axis of the aircraft. To hold a desired heading, the aviator must keep the rotor disk laterally level in relation to the horizon.

Turns are accomplished by banking (rolling) the aircraft about the longitudinal axis until the rotor disk is tilted laterally. Rate of turn is controlled by the degree the rotor disk is tilted. Aviators must learn to smoothly bank the aircraft to a degree of lateral tilt that will produce the desired rate of turn.

Stopping a turn is accomplished by smoothly rolling the aircraft level. Rollout is started before the desired heading is reached, so the turn is stopped on the desired heading.



Lift and weight are equal on aircraft A.

A and B have the same collective pitch and power setting, therefore, because weight and centrifugal force are acting together and increasing the load factor, vertical lift on B is less than weight.

Aircraft C has increased collective pitch and power to make vertical lift equal weight.

FIGURE 3-2. LOSS OF VERTICAL LIFT DURING TURNS.

Turning flight is accomplished by changing part of the vertical lifting force (A, fig 3-2) toward the horizontal. The turn produces centrifugal force which tends to move the aircraft toward the outside of the turn (B, fig 3-2). The resultant of weight and centrifugal force is outward and downward and is greater than the weight of the aircraft in A, figure 3-2. The resultant of weight and centrifugal force must be overcome by an addition of total lift or the aircraft will lose altitude during a turn. Aircraft C, figure 3-2, shows an increase of total lift as a result of increased collective pitch and power. Total lift now equals the total of centrifugal force and weight, so the aircraft will turn without losing altitude.

The resultant of weight and centrifugal force during turns produces an increased load factor on the aircraft. Load factor is the total load imposed on an aircraft, divided by the weight of the aircraft, and is expressed in G units. Load factor during a turn varies with the angle of bank (fig 3-3). Airspeed during a turn does not affect load factor, because for a given bank angle the rate of turn decreases with increased airspeed, resulting in no change of centrifugal force. Note that for a 60-degree bank, the load factor for any aircraft is 2 Gs regardless of airspeed (fig 3-3). This means that a 10,000-pound aircraft in a 60-degree bank will, in effect, exert 20,000 pounds of force on the aircraft structure. Bank angles

up to 30° produce only moderate increases in *load factor* which are acceptable under most flight conditions. The load factor rises at an increasing rate for banks over 30° (fig 3-3), and may produce unacceptable disk loading depending upon the aircraft gross weight and flight conditions.

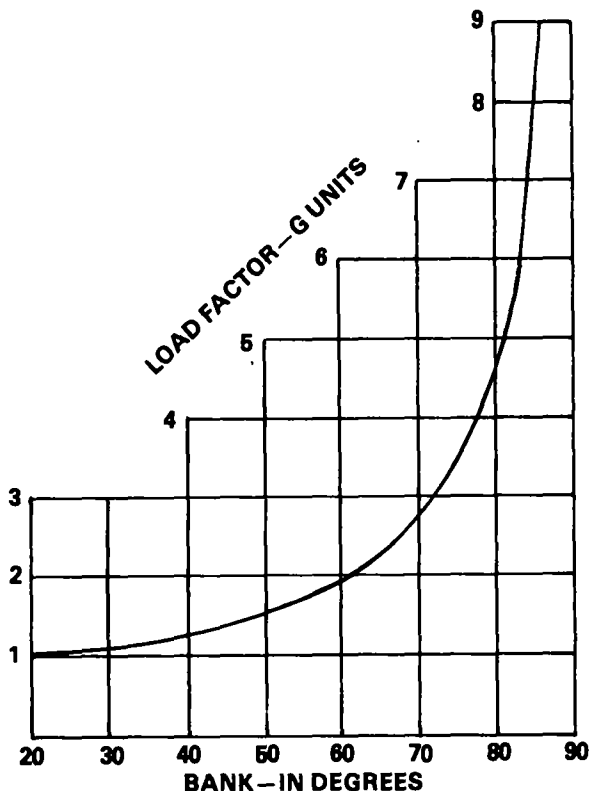


FIGURE 3-3. LOAD FACTORS IN VARIOUS ANGLES OF BANK DURING LEVEL TURNS.

POWER CONTROL AND RESULTING ALTITUDE, CLIMB, OR DESCENT

Altitude is a result of power control. To hold a desired altitude or make changes of altitude, the aviator must apply the power

settings that will produce the desired climb or descent when combined with the possible combinations of attitude and airspeed. Power settings that are normal for hover, climb, cruise, slow cruise, and descent must be used if precise control of altitude is desired. The pilot must also be able to adjust power to compensate for variation in atmospheric conditions and aircraft gross weight.

For a given attitude and airspeed, there is a power setting that will maintain altitude. If a climb is desired with a constant attitude and airspeed, power must be increased above that required to maintain altitude. If a descent is desired with constant attitude and airspeed, power must be reduced below the power required for maintaining altitude.

A constant altitude is maintained by minor pitch attitude adjustments and by power adjustments as necessary. After the altitude is stabilized and the desired airspeed is established, any deviation from altitude will result in an airspeed change as long as the altitude is changing. When the altitude is again stabilized, the airspeed will return to its previous indication provided the power is maintained at the previous setting. If airspeed is high due to loss of altitude, the excess airspeed may be used to return the aircraft to the desired altitude and airspeed by an upward pitch attitude adjustment. Conversely, with a gain in altitude and an accompanying loss of airspeed, the excess altitude may be utilized by a downward pitch attitude adjustment to return the aircraft to the desired airspeed and altitude.

HEADING CONTROL AND THE ANTITORQUE PEDALS

The primary purpose of the antitorque pedals is to counteract torque. However, the antitorque system usually is designed to have surplus thrust, far beyond that required to counteract torque. This additional thrust, designed into the tail rotor system, is used to provide positive and negative thrust for taxi direction control and to counteract the crosswind effect on the fuselage during hovering operations. In certain helicopter configurations, care must be exercised in using the thrust power of the antitorque system, since damage to the tail pylon area can result from overstress during fast rate hovering pedal turns and during taxi conditions over rough ground.

There are three separate modes of control for correct pedal use. Each of these modes should be analyzed and treated separately by the aviator.

□ The *first* group includes normal helicopter operations below 50 feet, during which the fuselage is alined with a distant point. This group includes taking off to and landing from a hover, the stationary hover, the moving hover, the takeoff and climb slip control, and the approach slip control.

□ The *second* group includes coordinated flight and all operations above 50 feet which require pedal use to aline and hold the fuselage into the relative wind.

□ The *third* group includes proper pedal use in turns. Coordinated turns (at altitude) require the proper use of pedals to keep the fuselage into the relative wind as the bank is initiated, established, and maintained.

Heading and track control for operations below 50 feet.

□ Taking off to and landing from a hover require that pedals be repositioned to hold and maintain the nose alinement with a distant reference point. The aviator uses an imaginary line to a distant object and applies pedal to position and maintain the line of sight from his seat through the cyclic and gap between his pedals (fig 3-4).

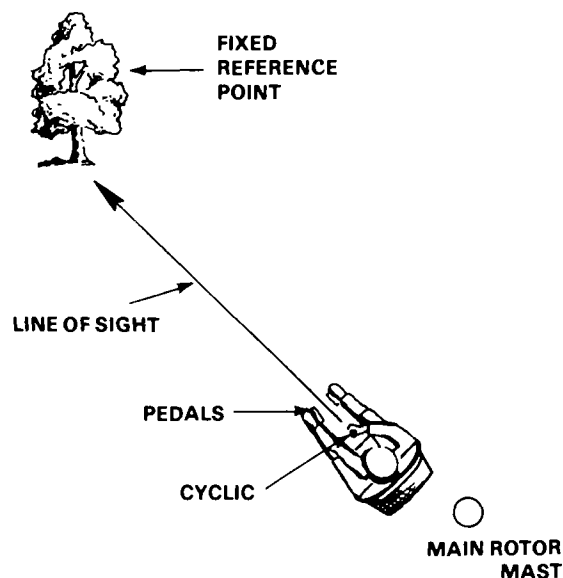


FIGURE 3-4. HEADING ALINEMENT DURING HOVERING.

Aviators in either seat use the same distant reference point with no appreciable error. Fuselage alinement to hovering or takeoff direction is shown in figure 3-5.

□ During the moving hover and the initial climb to 50 feet, pedals control heading as in figure 3-5; and cyclic control is used for direction and lateral positioning over the intended track as in figure 3-6. Using peripheral vision (and cross-check), the helicopter should be positioned with lateral cyclic so the imaginary line is seen running through position 1 (fig 3-6) during taxi or run on landings, and position 2 for hovering and climb through 20 feet. The line should be seen between pedals as shown at position 3 for all altitudes over 20 feet, with all track reference points lined up and passing between pedals in passage over each point.

□ In crosswind operations, the combined use of pedals and cyclic as described above results in a side slip, commonly referred to as a slip. The aviator does not consciously think "slip," for he is automatically in a true slip if he holds the fuselage alined on a distant object with pedals (fig 3-4) and maintains positioning over the line with cyclic (fig 3-6).

Heading and track control for operations above 50 feet.

□ For coordinated flight above 50 feet, the pedals assume a purely antitorque role and are promptly repositioned to a climb pedal setting upon reaching 50 feet. This pedal action alines the fuselage with the relative wind, rather than with a distant object.

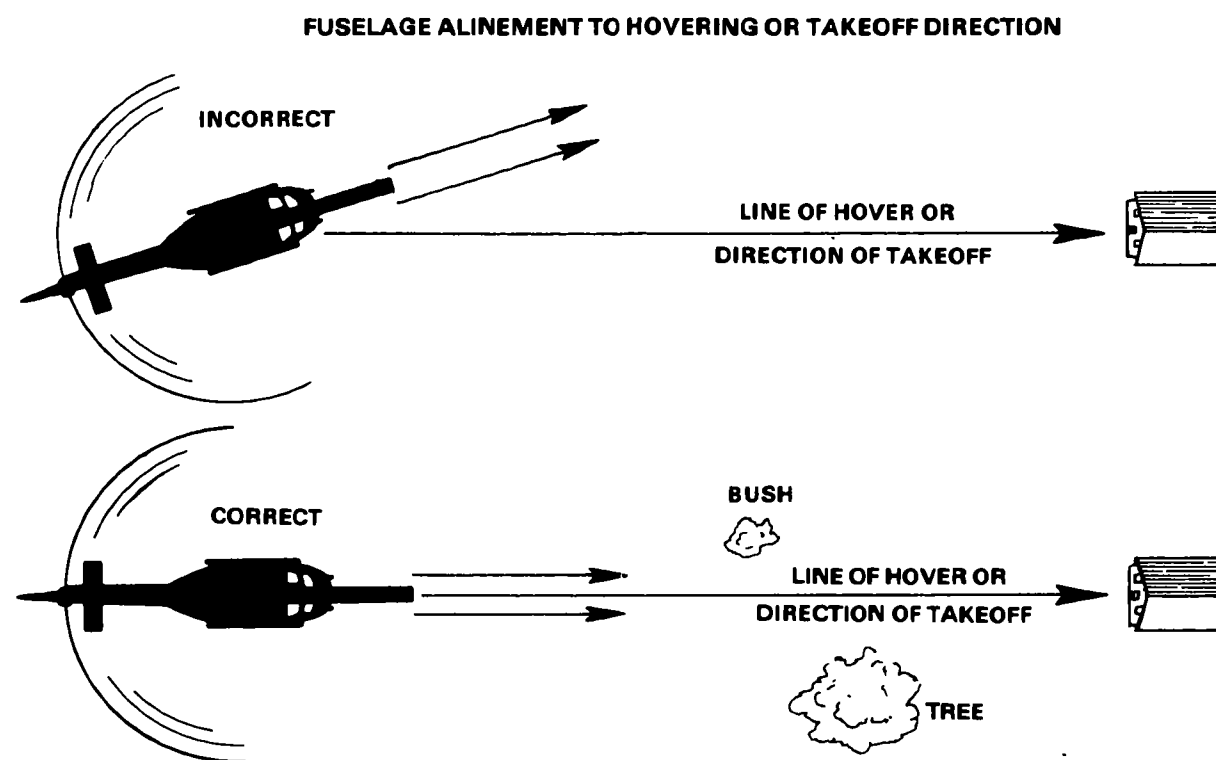


FIGURE 3-5. USE OF REFERENCES FOR HEADING CONTROL BELOW 50 FEET.

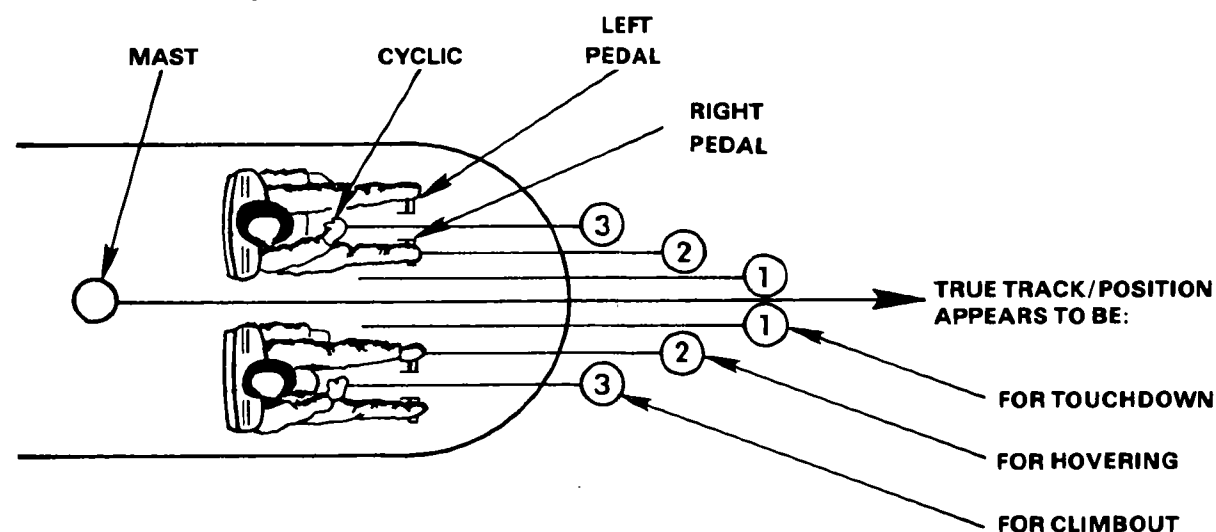


FIGURE 3-6. LATERAL POSITIONING REQUIRED TO MAINTAIN DESIRED GROUND TRACK.

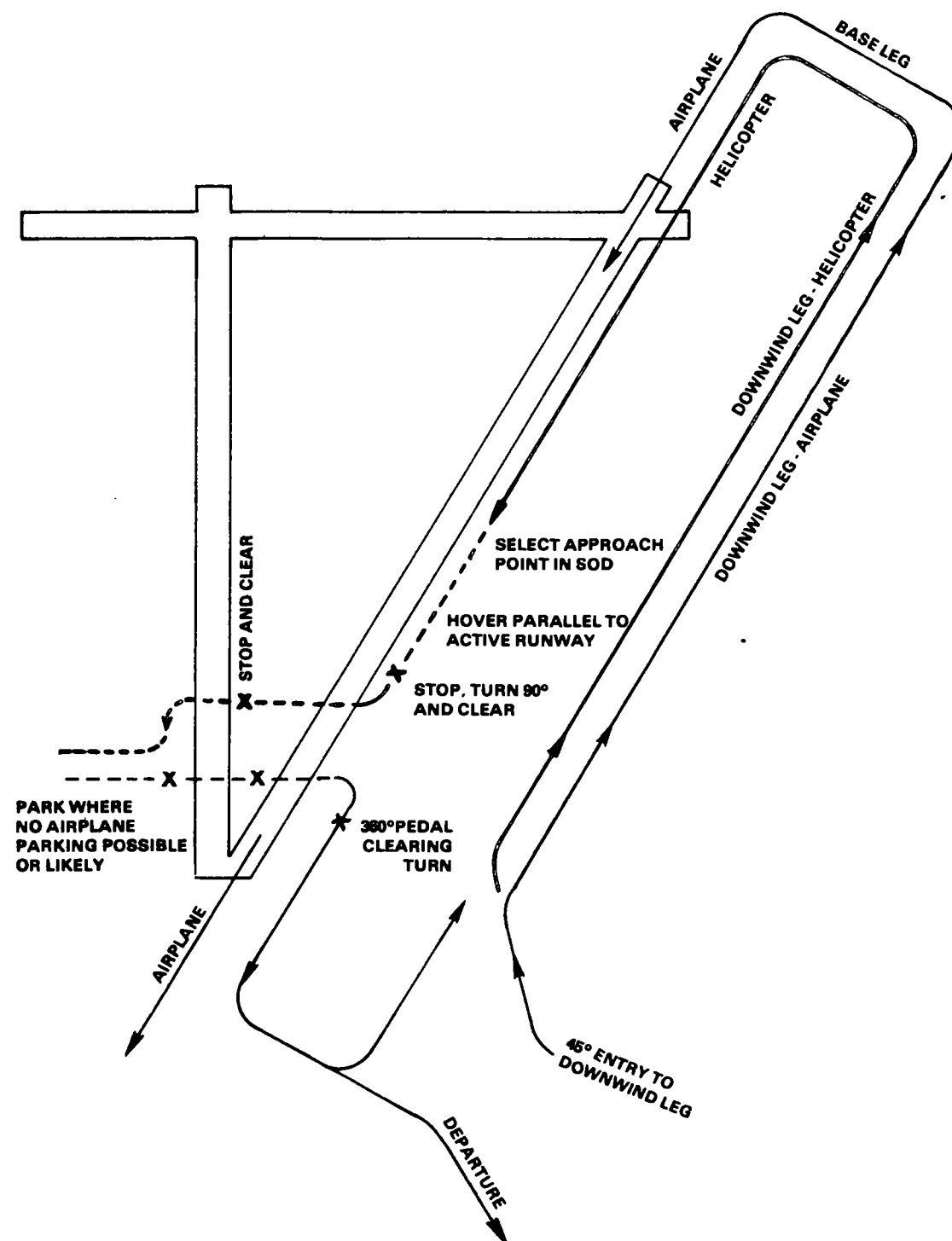


FIGURE 3-7. TYPICAL TRAFFIC PATTERN.

OPEN FOR
FOLDOUT

• The helicopter is now in coordinated flight, during which the cyclic controls fuselage heading; the rotor disk is level laterally; and the ball is centered.

• The track is now controlled by a coordinated cyclic bank and turn to a heading that will result in the desired track. Tracking toward and over selected ground reference points will cause these reference points to pass directly under the aviator's seat cushion.

□ Power changes require sufficient coordinated pedal to prevent the fuselage from yawing left or right. When the power change is completed, cross-check the new pedal setting and lateral trim of the fuselage.

□ Generally, the average single rotor helicopter will have pedal settings which are normal for various power/speed combinations. Coordinate these settings with power changes and hold in cross-check (for all operations and coordinated flight above 50 feet).

□ Rigging of pedal control linkage will vary in helicopters of the same type. Therefore, in steady climb, cruise, descent, or autorotation, with pedals set, cross-check:

• Turn-and-slip indicator for a centered ball. Pedal into the low ball and note the exact pedal setting required when ball is centered.

• Door frames or windshield frames for lateral level trim. Pedal into the low side and note the exact pedal setting required.

○ Main rotor tip-path plane. It should be the same distance above the horizon on each side. For level rotor, pedal into the low side.

□ In semirigid main rotor configurations, note the lateral hang of the fuselage at a hover (into the wind). If the fuselage is not level, due to a lateral CG displacement, then the one-side low condition must be accepted as level; thereafter, in flight (air work over 50 feet) adjust pedals for a lateral trim of one-side low as existed at a hover. Even though the fuselage is one-side low, the rotor is laterally level to the horizon, and the helicopter is in trimmed flight.

Pedal use in turns. Use of pedal to enter and maintain a turn requires study and experiment for the particular helicopter being flown.

□ To determine if pedal is required for a coordinated entry to bank and turn—

• Start at cruise airspeed with the correct pedal setting for lateral trim in straight-and-level flight.

○ Begin a bank with cyclic only. Use no pedal.

○ Note whether the nose turns in proportion to the bank.

□ If the nose begins to turn as the bank is initiated, no pedal is required for the entry to a turn in this helicopter.

□ If the nose does not begin to turn as the bank is initiated, use only that pedal required to make the nose turn in proportion to the bank and entry.

☐ After the bank is established, anticipate the normal requirement in all helicopters to require a slight pedal pressure in the direction of the turn for coordinated flight and a centered ball.

TRAFFIC PATTERN

A traffic pattern is useful to control the flow of traffic, particularly at nonradio-controlled airports or landing areas. It affords a measure of safety, separation, protection, and administrative control over arriving, departing, and circling aircraft. During nontactical training, a precise traffic pattern is flown to promote knowledge, planning, prediction, and flight discipline. All pattern procedures must be strictly followed so that every aviator working in the circuit and transient aviators arriving and departing, can determine at a glance the intentions of the other aviators.

When approaching a radio-controlled airport in a helicopter, it is possible to expedite traffic by stating, for example:

☐ (Call sign or aircraft serial number) Army helicopter 16123.

☐ (Position) 10 miles east.

☐ (Request) for landing and hover to. . .

The tower will often clear you direct to an approach point or to a particular runway intersection nearest your destination point. At uncontrolled airports, adhere strictly to standard practices and patterns.

Figure 3-7 depicts a typical nontactical traffic pattern with general procedures

outlined. If there is no identifiable helicopter traffic pattern, set up one inside the normal airplane pattern. Use touchdown and takeoff points to one side of the active runway. If you intend to land on the runway, approach to the near end; then hover clear of the runway immediately.

To fly a good traffic pattern, visualize a rectangular ground track and—

☐ Follow good outbound tracking on takeoff and climbout, with steady climb airspeed.

☐ Turn usually less than 90° for drift correction on the turn to crosswind leg, so as to track 90° to the takeoff leg.

☐ Select a point on the horizon for turn to downwind leg, so as to fly a track parallel to the takeoff and landing direction. Maintain a constant airspeed and altitude.

☐ Turn usually more than 90° for drift correction on the turn to base leg. Change attitude to slow cruise to establish approach entry airspeed. Change power and pedals to descend at approximately 500 feet per minute, or to lose 5 miles per hour for each 100 feet of descent. Watch far reference point for turn to final approach leg (fig 3-8).

☐ Turn short or beyond 90° on the turn to final, depending upon the crosswind condition. Before entering approach (or not later than the last 50 feet of the approach), establish a slip with fuselage on line with the line of approach and the helicopter positioned over the line of approach.

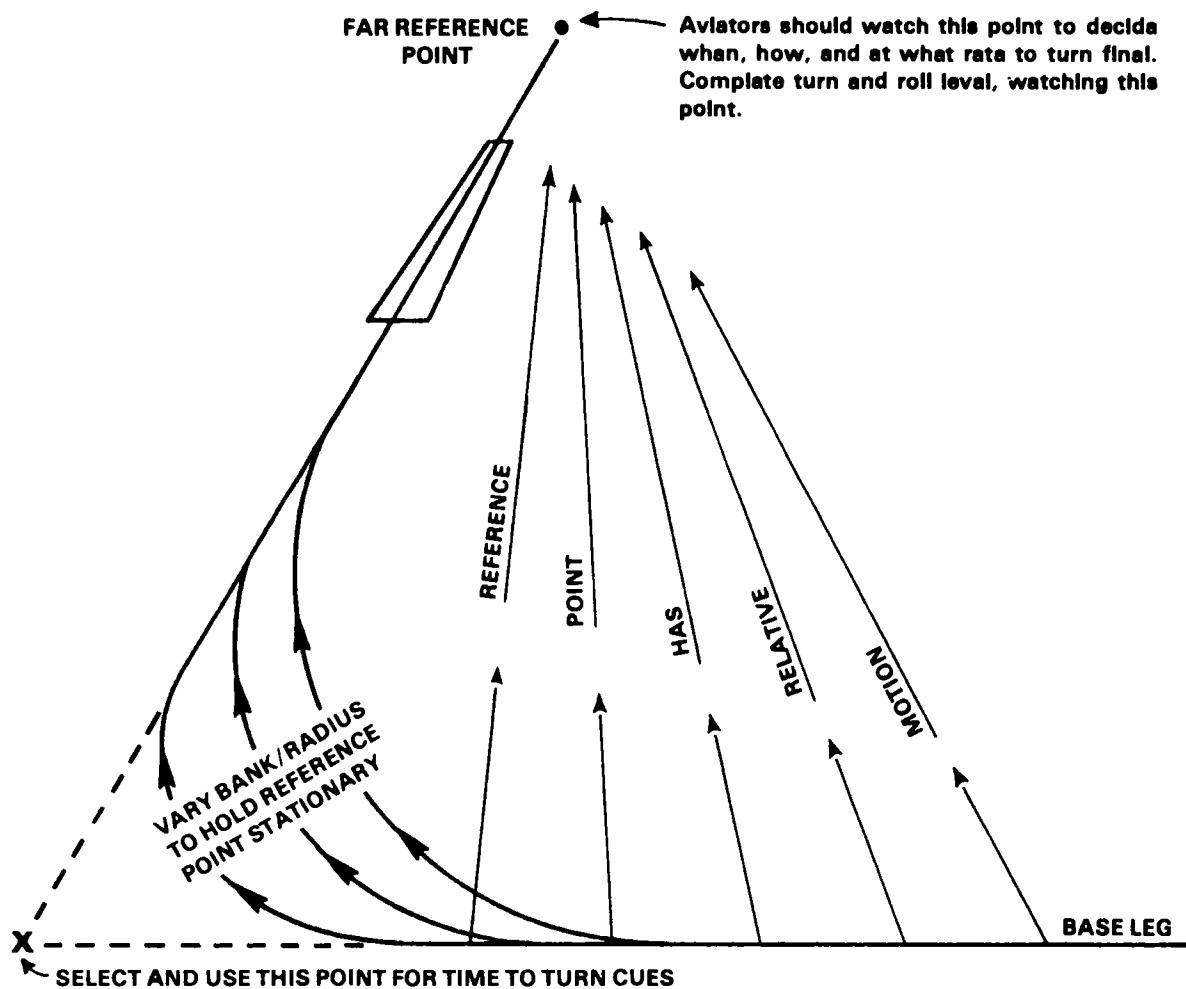


FIGURE 3-8. TURN TO FINAL APPROACH.

CHAPTER 4

FIELD OPERATIONS

BASIC CONSIDERATIONS

For the purpose of this discussion, a *confined area* is any area where the flight of the helicopter is limited in some direction by terrain or the presence of obstructions, natural or manmade. For example, a clearing in the woods, the top of a mountain, the slope of a hill, or the deck of a ship can each be regarded as a confined area.

Takeoffs and *landings* should generally be made into the wind to obtain maximum airspeed with minimum groundspeed. Situations may arise which modify this general rule.

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Turbulence is defined as smaller masses of air moving in any direction contrary to that of the larger airmass. Barriers on the ground and the ground itself may interfere with the smooth flow of air. This interference is transmitted to upper air levels as larger, but less intense, disturbances. Therefore, the greatest turbulence usually is found at low altitudes. Gusts are sudden variations in wind velocity. Normally, gusts are dangerous only during flight at very low altitudes. The aviator may be unaware of the gust, and its cessation may reduce lift, causing the aircraft to sink or descend abruptly. Gusts cannot be planned for or anticipated. Turbulence, however, can generally be predicted. Turbulence normally exists during moderate to strong wind conditions in the following places:

☐ Near the ground on the downwind side of trees, buildings, or hills. The turbulent area is always relative in size to that of the obstacle, and relative in intensity to the velocity of the wind (fig 4-1).

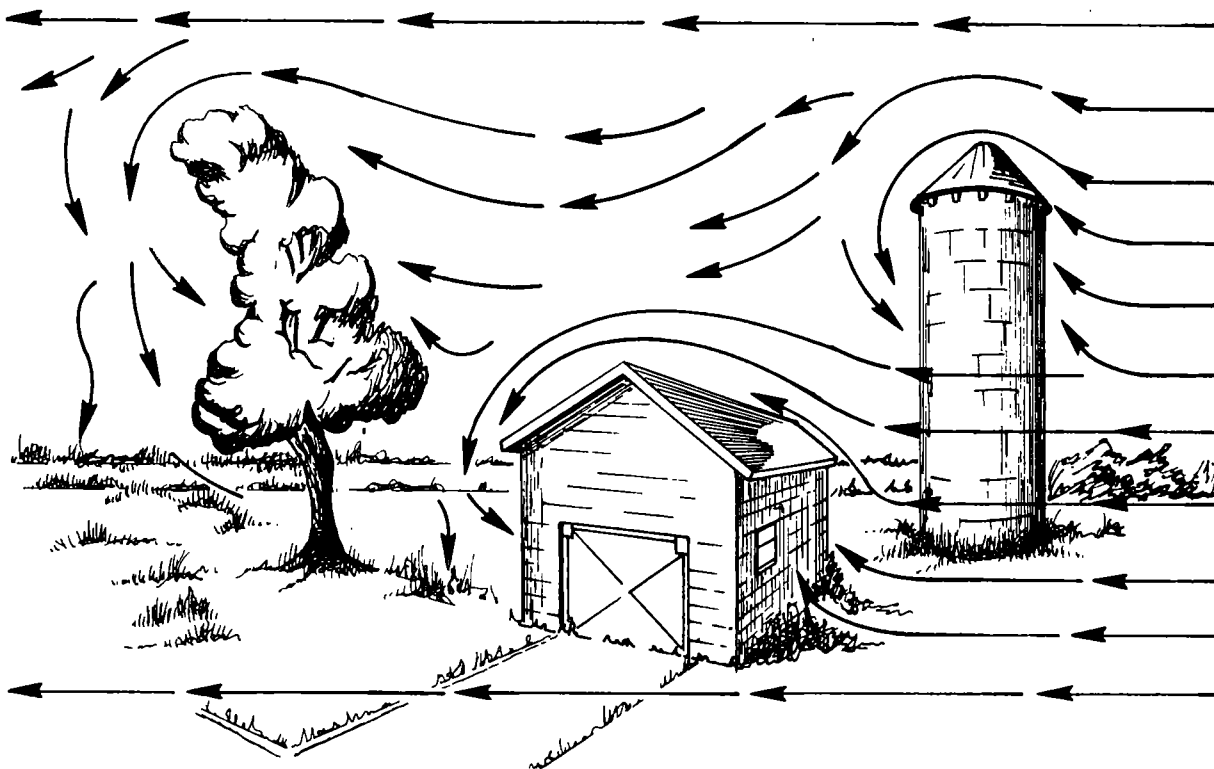


FIGURE 4-1. AIR TURBULENCE (BUILDING AND TREES).

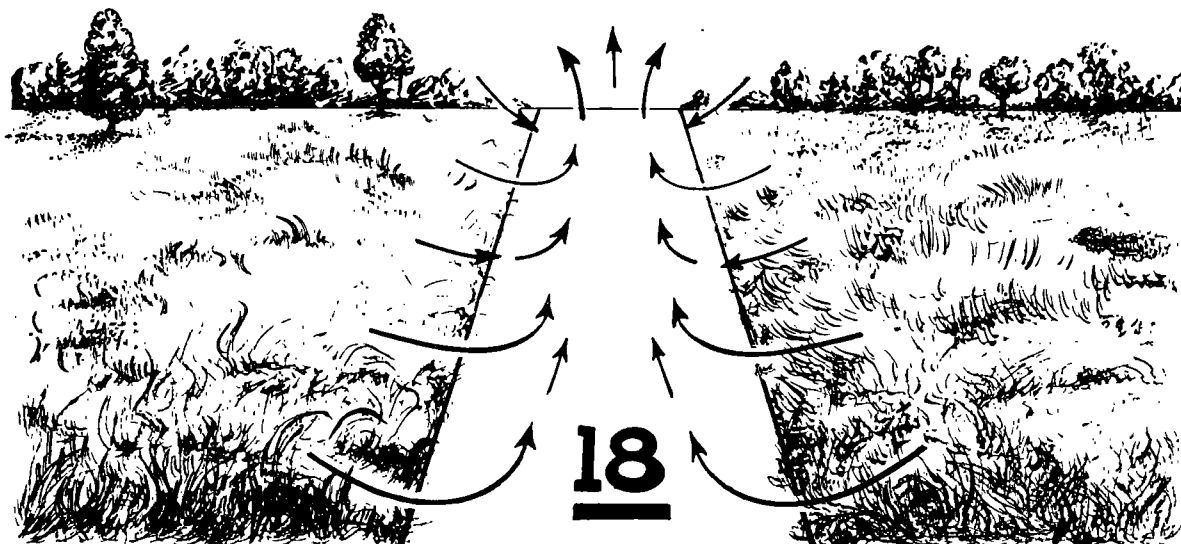


FIGURE 4-2. AIR TURBULENCE (DISSIMILAR GROUND).

☐ On the ground on the immediate upwind side of any solid barrier such as leafy trees, buildings, etc. This condition is not generally dangerous unless the wind velocity is approximately 17 knots or higher.

☐ In the air, over and slightly downwind of any sizable barrier, such as a hill. The size of the barrier and the wind velocity determine the height to which the turbulence extends.

☐ At low altitudes on bright sunny days near the border of two dissimilar types of ground, such as the edge of a ramp or runway bordered by sod (fig 4-2). This type of turbulence is caused by the upward and downward passage of heated or cooled air.

RECONNAISSANCE

A *high* and *low reconnaissance* should be conducted prior to landing in an unfamiliar area.

☐ *High Reconnaissance.* The purpose of a high reconnaissance is to determine suitability of the landing area, locate barriers and estimate their wind effect, select approach and departure axis, select a point for touchdown, and plan the flight-path for approach and takeoff. Altitude, airspeed, and flight pattern for the high reconnaissance are governed by wind and terrain features, including availability of forced landing areas. The reconnaissance should be low enough to permit study of the general area, yet not so low that attention must be divided between studying the area and avoiding obstructions to flight. It should be high enough to afford a reasonable chance of making a successful forced landing in an emergency, yet not so high that the proposed area cannot be studied adequately. A high reconnaissance

is impractical during conditions that require terrain flight, because the aviator would have to climb and expose the aircraft to the threat for an unacceptable period of time.

☐ *Low Reconnaissance.*

● Except when a running landing is necessary, the low reconnaissance and approach can often be conducted together. To accomplish this, the aviator studies his approach path and the immediate vicinity of his selected touchdown point as he approaches; however, before loss of effective translational lift, or prior to descending below the barrier, he must decide whether the landing can be completed successfully. Never land in an area from which a successful takeoff cannot be made. The low reconnaissance should confirm what was learned from the high reconnaissance.

● When a running landing is contemplated because of load or high density altitude conditions, a "fly-by" type of low reconnaissance is made. Airspeed is adequate to maintain effective translational lift at an altitude sufficient to clear all obstacles and allow the aviator to concentrate on terrain features. The intended landing area should be checked for obstacles and/or obstructions in the approach path or on the landing site; and the point of intended touchdown must be selected.

● A low reconnaissance can be conducted during an approach from terrain flight; however, the landing area will normally be visible for only a very short time prior to touchdown. A longer period of time for low reconnaissance is available if a

circling approach from terrain flight can be made. Aviators must evaluate the tactical situation and determine whether a circling approach will expose them to the threat.

CONFINED AREA OPERATIONS

□ *Approach.*

- The confined area approach begins with the high reconnaissance. Plan the approach by taking into consideration several different and sometimes conflicting factors. Account for wind conditions and the best possible advantage to be obtained from them. Consider the height of barriers, and identify the lowest obstruction which would provide the best entry into the area under favorable wind conditions. Where possible, plan the flightpath to place the helicopter within reach of those areas most favorable for a forced landing. When it is not possible to keep the area in sight, specific reference points along the approach path should be selected which will keep the aviator from losing the area completely.

- Point-of-touchdown should be as far beyond the barrier as practicable to insure against the approach becoming too steep. The final stages of the approach, however, should be conducted short of downdrafts and turbulence which may be encountered at the far end of the area.

- The angle of descent should be steep enough to permit clearance of the barrier, but normally not greater than a steep approach (fig 4-3).

- Terminate the approach to the ground when surface conditions permit.

□ *Ground Operations.* Before the helicopter is operated within the area, a ground reconnaissance should be conducted to determine suitability of the area. This reconnaissance can be made from the cockpit or by conducting a walk-around reconnaissance of the area.

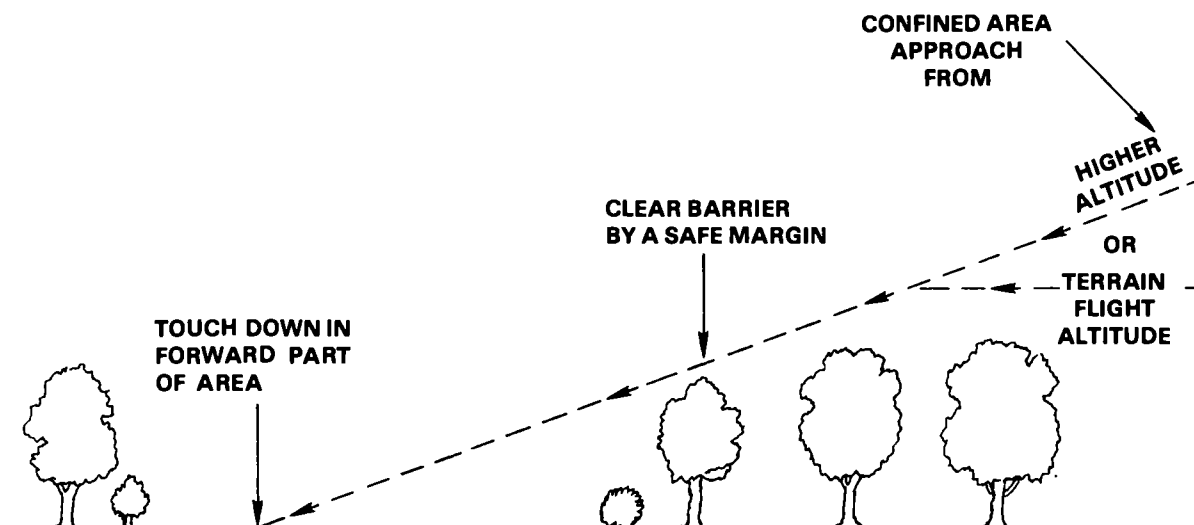


FIGURE 4-3. CONFINED AREA APPROACH AND LANDING.

□ Takeoff.

- Position the helicopter for takeoff, taking advantage of wind, barriers, and anticipated forced landing areas on takeoff.

- Perform power checks and before-takeoff checks.

- Form an imaginary line from a point on the leading edge of the helicopter (e.g., gear) to the highest barrier that must be cleared. This line of ascent will be flown using only that power that is required to clear the obstacle by a safe distance (fig 4-4).

- As the barrier is cleared, the attitude of the helicopter should be adjusted to achieve a normal climb airspeed and rate of climb.

PINNACLE AND RIDGELINE OPERATIONS

A *pinnacle* is an area from which the ground drops away steeply on all sides. A

ridgeline is a long area from which the ground drops away steeply on one or two sides, such as a bluff or precipice. The absence of pinnacle barriers does not necessarily lessen the difficulty of pinnacle operations (fig 4-5). Updrafts, downdrafts, and turbulence may still present extreme hazards. Landing areas may be small with barely enough room for a safe touchdown.

Climb to a pinnacle or ridgeline should be executed on the windward side to take advantage of updrafts (A, fig 4-5). Approach flightpath should be parallel to a ridgeline and as nearly into the wind as possible. Groundspeed during the approach is more difficult to judge because visual references are further away than during approaches over trees or flat terrain. Avoid leeward turbulence and keep the helicopter within reach of a forced landing area as long as practicable. Load, altitude, wind conditions, and terrain features determine the angle to use in the final part of the approach. If wind velocity makes cross-wind landing hazardous, make a low

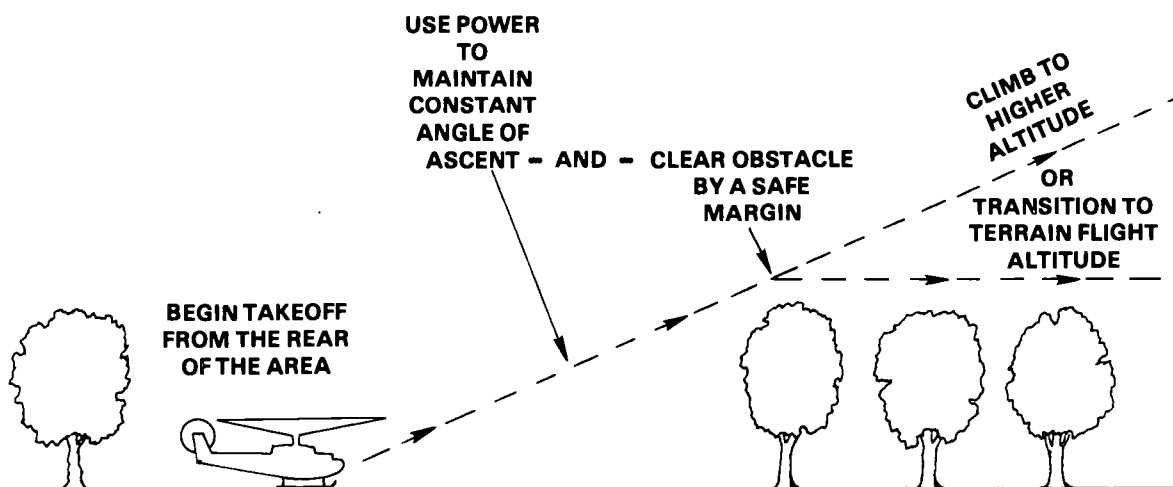


FIGURE 4-4. CONFINED AREA TAKEOFF.

coordinated turn into the wind just prior to landing.

CAUTION: Remain clear of downdrafts on the downwind side (B, fig 4-5).

Landing on a pinnacle should be made to take advantage of the long axis of the area when wind conditions permit. Touchdown should be made in the forward portion of the area and a stability check should be accomplished to insure the gear is on firm terrain that will support the weight of the helicopter safely.

Since a pinnacle is higher than immediate surrounding terrain, gaining airspeed

on takeoff is more important than gaining altitude. The airspeed gained will cause a more rapid departure from the slopes of the pinnacle. In addition to covering unsafe ground quickly, a higher airspeed affords a more favorable glide angle; and thus contributes to the chances of reaching a safe area in the event of forced landing. If no suitable area is available, a higher airspeed will permit the aviator to execute a deceleration and decrease forward speed prior to autorotative landing. After clearing the pinnacle, no attempt should be made to dive the helicopter down the slope. This will result in a high rate of descent and may prevent a successful autorotative landing.

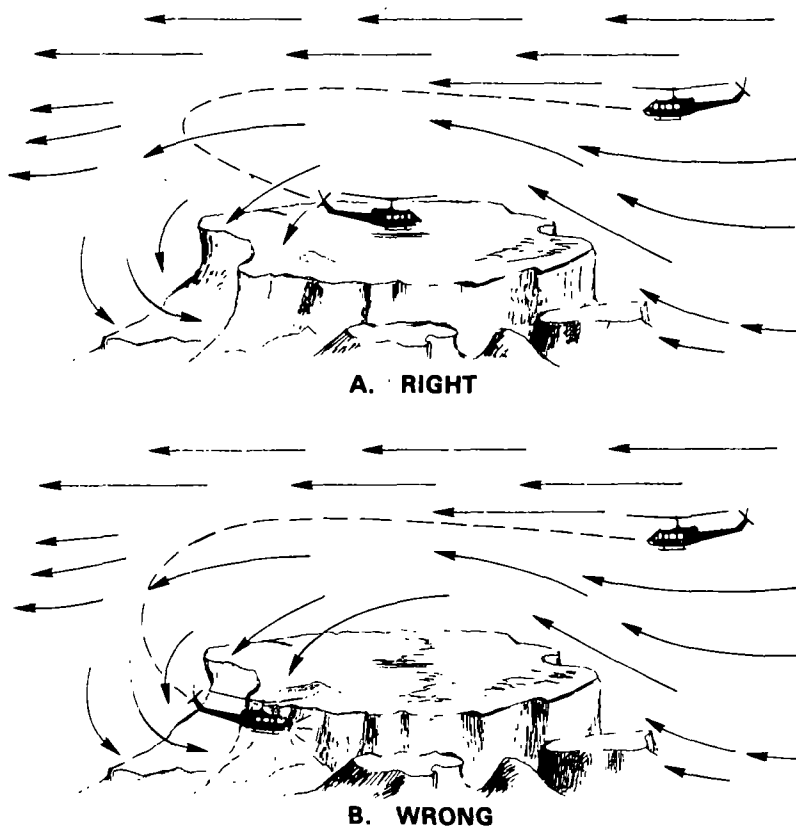


FIGURE 4-5. PINNACLE APPROACH.

TERRAIN FLIGHT CONSIDERATIONS

□ *Takeoffs* from confined areas, or other remote areas, are not significantly different when transition is made into terrain flight rather than into flight at a higher altitude. The direction of takeoff will be determined by the enemy situation, wind, density altitude, and the long axis of the area. If the threat of enemy observation is high, the takeoff should be made taking full advantage of available terrain and vegetation for masking. If the threat is not a factor, takeoff is made into the wind, over the lowest barriers, taking advantage of the long axis of the area. As the barriers are cleared, adjust attitude and power as necessary to transition into the desired terrain flight altitude and airspeed.

□ *Landings* into confined areas are not significantly different when transition is made from terrain flight rather than from a higher altitude. Because a high reconnaissance is not possible during terrain flight, more reliance is placed on flight planning to learn about the landing zone. Ground units in the landing zone should be contacted early for landing instructions while the aircraft is still several miles away. Airspeed should be decreased from cruise to approach speed early enough to permit a smooth transition into the approach when the landing zone comes into view. When flying NOE or contour, the approach angle may be intercepted at a very low altitude, leaving little time to transition into the approach. Entry speed may have to be decreased prior to intercepting the approach angle to prevent overshooting the landing zone.

□ *Approaches* to pinnacles or ridgelines will probably be started at a lower altitude than the altitude of the landing zone. A climb to the landing zone is made while maintaining a minimum of 40 knots airspeed. As the landing zone is approached, reduce airspeed when necessary to attain a safe rate of closure to the touchdown area.

SLOPE OPERATIONS

□ *General.* When a helicopter rests on a slope, the mast is perpendicular to the inclined surface, while the plane of the main rotor must parallel the true horizon or tilt slightly upslope. Thus the rotor tilts with respect to the mast. Normally, the cyclic control available for this rotor tilt is limited by cyclic control stops, static stops, mast bumping, or other mechanical limits of control travel. These control limits are reached much sooner in downslope wind conditions. Also, when the hovering helicopter hangs with one side low, there will be less control travel when landing with the low side upslope. Therefore, a slope landing site which was used once may not be acceptable with a different wind or CG helicopter loading. Also, conditions that permitted a slope landing may have changed to cause very hazardous conditions for takeoff (e.g., wind or CG loading change).

• *Approach.* The approach to a slope may not materially differ from the approach to any other landing area. However, the slope may obstruct wind passage and cause turbulence and downdrafts. Allowance must be made for wind, barriers, and forced landing sites.

○ *Landing upslope or cross-slope.* If a helicopter is equipped with wheel type landing gear, brakes must be set prior to making a landing. The landing is then usually made heading upslope. With skid-type gear, slope landings should be made cross-slope. This type landing requires careful and positive control touch. The helicopter must be lowered from the true vertical by placing the uphill skid on the ground first. The downhill skid is then lowered gently to the ground. Corrective cyclic control is applied simultaneously to keep the helicopter on the landing point. The aviator must maintain positive heading control on a forward reference point and normal operating RPM until the landing is completed. To avoid mast bumping, sliding downslope, or rollover, the landing attempt should be aborted if the aviator runs out of cyclic control travel before the downhill skid is firmly on the ground.

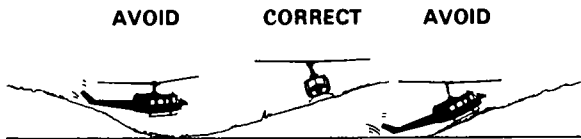


FIGURE 4-6. SLOPE OPERATIONS.

○ *Landing downhill.* Landing downhill (fig 4-6) is not recommended with single main rotor type helicopters because of the possibility of striking the tail rotor on the ground.

○ *Landing uphill.* If an uphill landing (fig 4-6) is necessary, landing too near the bottom of the slope may cause the tail rotor to strike the ground. In this case, and when landing downhill, the mission may sometimes be completed at a low hover.

○ *Takeoff from a slope.* To lift off from a slope, the aviator moves cyclic control toward the slope and slowly adds collective pitch. The downhill skid must first be raised to place the helicopter in a level attitude before lifting it vertically to a hover.

□ *Dynamic Rollover Characteristics.* During slope or crosswind landing and takeoff maneuvers, the helicopter is susceptible to a lateral rolling tendency called *dynamic rollover*. Each helicopter has a critical rollover angle beyond which recovery is impossible. If the critical rollover angle is exceeded, the helicopter will roll over on its side regardless of cyclic corrections introduced by the pilot. The rate of rolling motion is also critical. As the roll rate increases, it reduces the critical rollover angle at which recovery is still possible. Depending on the helicopter, the critical rollover angle may change depending on which skid or wheel is touching the ground, crosswind component, lateral offsets in center of gravity, and left pedal inputs for torque correction (single rotor systems).

○ Dynamic rollover starts when the helicopter has only one skid or wheel on the ground and that gear becomes a pivot point for lateral roll (figs 4-7, 4-8). When this happens, lateral cyclic control response is more sluggish and is less effective than for the free hovering helicopter. The gear may become a pivot point for a variety of reasons, most of which are pilot induced. It may become caught on something projecting from the landing surface such as a bent piece of pierced steel planking (PSP). It could become stuck in soft asphalt or

DOWNSLOPE ROLLING MOTION

Excessive application of collective pitch in coordination with cyclic application into the slope. When the downslope skid is on the slope, excessive application of collective may result in the upslope skid rising sufficiently to exceed lateral cyclic limits and induce a downslope rolling motion.

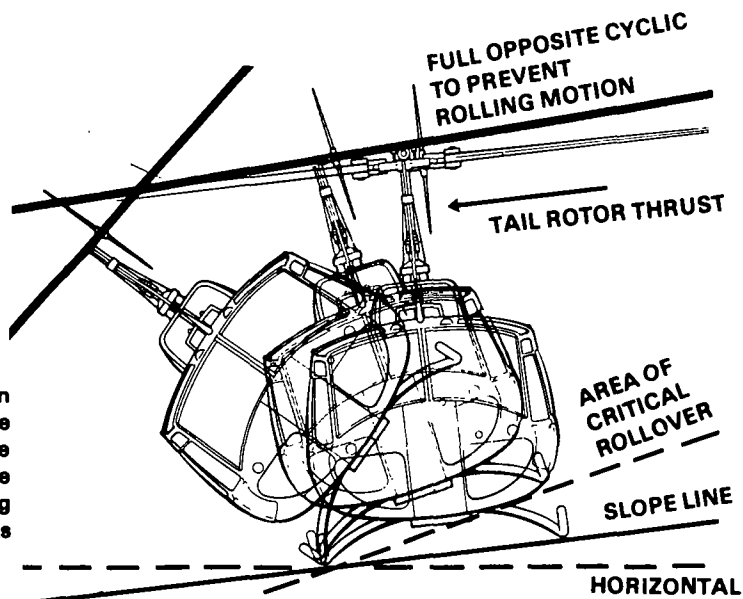


FIGURE 4-7. DOWNSLOPE ROLLING MOTION.

UPSLOPE ROLLING MOTION

Excessive application of cyclic into the slope, in coordination with collective pitch application. During landings or takeoffs, this condition results in the downslope skid rising sufficiently to exceed lateral cyclic control limits and an upslope rolling motion occurs.

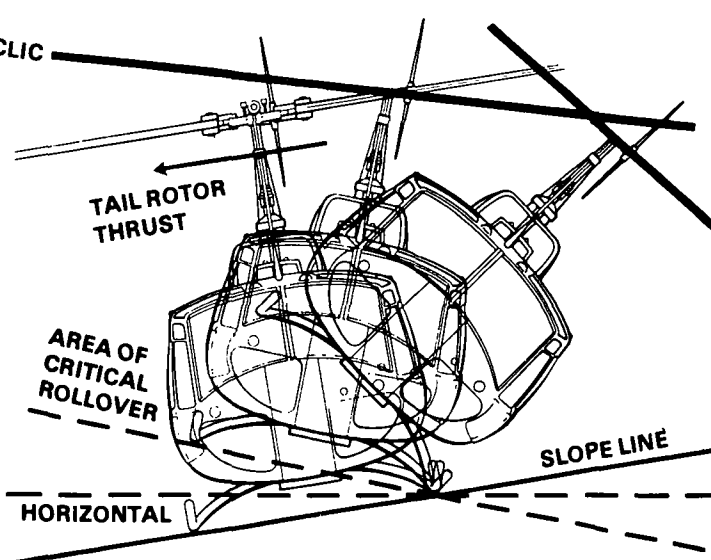


FIGURE 4-8. UPSLOPE ROLLING MOTION.

mud. It could be forced into the slope by improper landing or takeoff technique. Whatever the cause, if the gear becomes a pivot point, dynamic rollover becomes a definite possibility if subsequent pilot actions are incorrect.

- The tail rotor may contribute to the rolling tendency if cyclic is not correctly applied to counteract lateral tail rotor thrust. Crosswind can also contribute to rollover by causing sideward drift, or by further accentuating the aircraft bank angle needed to land on a slope.

- Application of collective pitch is more effective than lateral cyclic in controlling the rolling motion because it changes main rotor thrust. A smooth moderate collective pitch *reduction* may be the most effective way to stop a rolling motion. Collective must not be reduced so fast as to cause fuselage and rotor blade contact. Also, if the helicopter is on a slope and the roll starts to the upslope side, reducing collective too fast may create a high roll rate in the opposite direction. If collective reduction causes the downslope skid to hit the ground abruptly, the rate of motion may cause a roll or pivot about the downslope gear.

- Sudden increase of collective pitch in an attempt to become airborne may be ineffective in stopping dynamic rollover. If the skid that acts as a pivot point *does not* break free of the ground as collective is increased, the rollover tendency will increase and become worse. If the skid *does* break free of the ground as collective is increased, it can cause an abrupt rolling movement in the opposite direction because of pendulum effect. This movement may also become uncontrollable.

- When performing maneuvers with one skid on the ground, care must be taken to keep the helicopter trimmed, especially laterally. Control can be maintained if the pilot maintains trim, does not allow lateral roll rates to become rapid, and keeps the bank angle from exceeding the critical rollover angle for the helicopter. The pilot must fly the helicopter into the air smoothly with only small changes in pitch, roll, and yaw. Untrimmed moments must be avoided.

□ *Prevention of Upslope Rollover During Liftoff.* Upslope rollover characteristics are possible during liftoff. Upslope rollover can result from excessive use of cyclic to hold the upslope skid against the slope. Improper use of collective pitch could then result in a rapid pivoting around the longitudinal axis of the upslope landing gear to the point of rollover. To prevent upslope rollover, the aviator should cautiously lift the downslope side of the helicopter to the level point and simultaneously work the cyclic control to neutral. Once the cyclic is neutral and/or the upslope landing gear has *no side pressure applied*, the aviator is cleared for a vertical liftoff to a hover and then to a normal takeoff.

□ *Prevention of Downslope Rollover During Landing.* Downslope rollover is caused by the slope tilting the helicopter beyond the cyclic control limits. If the slope (wind or CG conditions) exceeds lateral cyclic control limits, the mast forces the rotor to tilt downslope. This causes the resultant rotor lift to have a downslope component, even with full upslope cyclic applied. To prevent downslope rollover during landing, the aviator should slowly

descend vertically to a light ground contact with the upslope skid. While observing lateral level reference frames, he should pause while checking positive heading control. Then using careful collective pitch control, he should slowly and cautiously lower the downslope skid. As the cyclic stick nears the lateral stop, he should pause to compare the distance to go with the lateral control travel remaining. (See limits in appropriate Operator's Manual.) If it appears that the cyclic will contact the upslope control stop before the downslope skid is firmly on the ground, he should return the helicopter to a level attitude and abort the slope landing. He should then lift off and move a few feet for another attempt on a lesser slope.

☐ *Prevention of Downslope Rollover During Liftoff.* If a landing was inadvertently completed on an excessive slope, and during an attempt to liftoff the upslope skid tends to rise, the aviator should smoothly lower the collective pitch. The problem is that with full cyclic applied, the resultant lift of the main rotor is not vertical or directed upslope sufficiently to raise the downslope skid. Therefore, if the upslope skid raises, the mast causes the resultant rotor lift to move further downslope. This increases the downslope roll tendency which increases with added collective pitch. The corrective action is to reduce power at the first sign of lateral roll around the downslope skid. Before further liftoff attempts are made, appropriate aviator action may be to:

- Await different wind conditions.
- Change CG loading.

- Dig out under the upslope gear.
- Notify operations to send a recovery crew.

GENERAL PRECAUTIONS

Certain general rules apply to operations in any type of confined area, slope, or pinnacle. Some of the more important of these rules are:

☐ Know wind direction and approximate velocity at all times. Plan landings and takeoffs with this knowledge in mind.

☐ Plan the flightpath, both for approach and takeoff, to take maximum advantage of forced-landing areas.

☐ Operate the helicopter as near to its normal capabilities as the situation allows. The angle of descent should be no steeper than that necessary to clear existing barriers and to land on a preselected spot. Angle of climb in takeoff should be no steeper than that necessary to clear all barriers in the takeoff path.

☐ If low hovering is not made hazardous by the terrain, to minimize the effect of turbulence and to conserve power, the helicopter should be hovered at a lower altitude than normal when in a confined area. High grass or weeds will decrease efficiency of the ground effect; but hovering low or taking off from the ground will partially compensate for this loss of ground effect.

☐ Make every landing to a specific point, not merely into a general area. The more confined the area, the more essential

that the helicopter be landed precisely upon a definite point. The landing point must be kept in sight during the final approach, particularly during the more critical final phase.

☐ Consideration should be given to increases in terrain elevation between the point of original takeoff and subsequent areas of operation.

☐ Brakes (on wheeled helicopters) should be set prior to initiating the approach for a confined area landing, except for a running landing or when the landing area is known to be level. This precaution precludes unexpected roll after touchdown. A slope landing almost invariably results in a wheel roll unless the brakes are preset.

☐ In entering any restricted area, judge the diameter clearance of main rotor blades; but remain especially alert to prevent possible damage to the tail rotor. Not only must the angle of descent over a barrier clear the tail rotor of all obstructions, but caution must be exercised on the ground to avoid swinging the tail rotor into trees, boulders, or other objects. The aviator is responsible to see that personnel remain clear of the tail rotor at all times.

CHAPTER 5

TERRAIN FLIGHT

SECTION I. GENERAL.

THE HIGH THREAT ENVIRONMENT

The high threat environment is an enemy combat posture wherein modern, sophisticated weapons and techniques create a highly lethal situation with the intention of establishing control over territory and

airspace contiguous to that territory. Such a posture could include an array of weapons systems such as armor, field and air defense artillery, armed helicopters, and tactical fighters (fig 5-1). These weapons systems would be supplemented by electronic warfare equipment to include interception, jamming, and deception.

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FIGURE 5-1. THREAT WEAPONS.

To survive and accomplish the mission, Army aviation units must operate as part of the combined arms team. Ground forces can provide fires to suppress the enemy's air defense capability. The air defense umbrella provided by supporting and organic air defense units will assist aviation units in the area to survive against enemy aircraft. While the ground forces help the aviation unit maintain freedom of movement, the aviation forces will provide the ground forces mobility, airborne eyes and ears, and will help suppress the threats they operate against.

Tactics that Army aviation units will use to minimize detection by Threat forces include terrain flight, night operations, limited communication, tactical instrument flight, and frequent movement. The success of a unit in combat will be directly proportional to its ability to perform using these tactics and to operate as a member of the combined arms team. Proficiency in these essential tactics is the key to winning the first battle of the next war!

The specific threats and employment doctrine against which we will operate in the high threat environment are discussed in FM 90-1 and FM 1-2. We face a threat not only when in the air, but also when on the ground. This threat includes sophisticated air defense weapons and electronic warfare; attacks by high performance aircraft and attack helicopters; and the use of artillery to destroy our maintenance facilities and arming and refueling points. Basically, what the threat analysis reveals is that if an aircraft is exposed during flight, the enemy can locate and hit it. Due to the lethality of his weapons, if he can hit the aircraft, he can eliminate it from the

battlefield. *But he has the advantage only if we make the first mistake* of exposing the aircraft by not properly using the terrain, vegetation, darkness, weather, suppressive fires, smoke, or radar deterrents (chaff, jamming). The combat experience of 1972 in Vietnam; the knowledge gained from the 1973 Middle East War; and the results of aircraft survivability tests have proven that terrain flying can minimize the effectiveness of the enemy weapons systems. Simply stated, "*Terrain flying* is the fundamental element for mission success in the high threat environment."

GENERAL CONDITIONS FOR AVIATION OPERATIONS IN A HIGH THREAT ENVIRONMENT

- ☐ Units will operate as members of the combined arms team.
- ☐ Units will be required to conduct both day and night missions.
- ☐ Units will operate in adverse weather conditions.
- ☐ Enemy electronic warfare, especially jamming and voice deception, will be employed against aviation units.
- ☐ Units will often operate under conditions of radio silence.
- ☐ Attacks by enemy tactical fixed-wing aircraft and rotary-wing aircraft can be anticipated.
- ☐ Operations will be conducted in a conventional and nuclear and biological environment.
- ☐ Frequent attacks by enemy artillery can be expected.

WHAT IS TERRAIN FLYING?

TERRAIN FLYING IS FLIGHT IN THE FACE OF THE ENEMY. IT IS TO THE AVIATOR WHAT THE LOW CRAWL IS TO THE INFANTRYMAN—A MEANS OF SURVIVABILITY.

Specifically, *terrain flying* is the tactic of employing aircraft in such a manner as to use the terrain, vegetation, and manmade objects to enhance survivability by degrading the enemy's ability to visually, optically, or electronically detect the aircraft. The employment of this tactic requires a constant awareness of the capabilities and location of the enemy weapons systems and detection devices. Terrain flying of necessity involves flight close to the earth's surface and includes the tactical application of low-level, contour,

and nap-of-the-earth (NOE) flight techniques (fig 5-2) as appropriate to the enemy's capability to acquire, track, and engage the aircraft.

The definitions of each mode of terrain flight are—

☐ *Nap-of-the-Earth Flight*—Flight at varying airspeeds as close to the earth's surface as vegetation, obstacles, and ambient light will permit, while generally following the contours of the earth.

☐ *Contour Flight*—Flight at low altitude conforming generally to, and in close proximity to, the contours of the earth. It is characterized by varying airspeeds and altitude as dictated by vegetation, obstacles, and ambient light.

☐ *Low-level Flight*—Flight generally carried out above obstacles, but at an

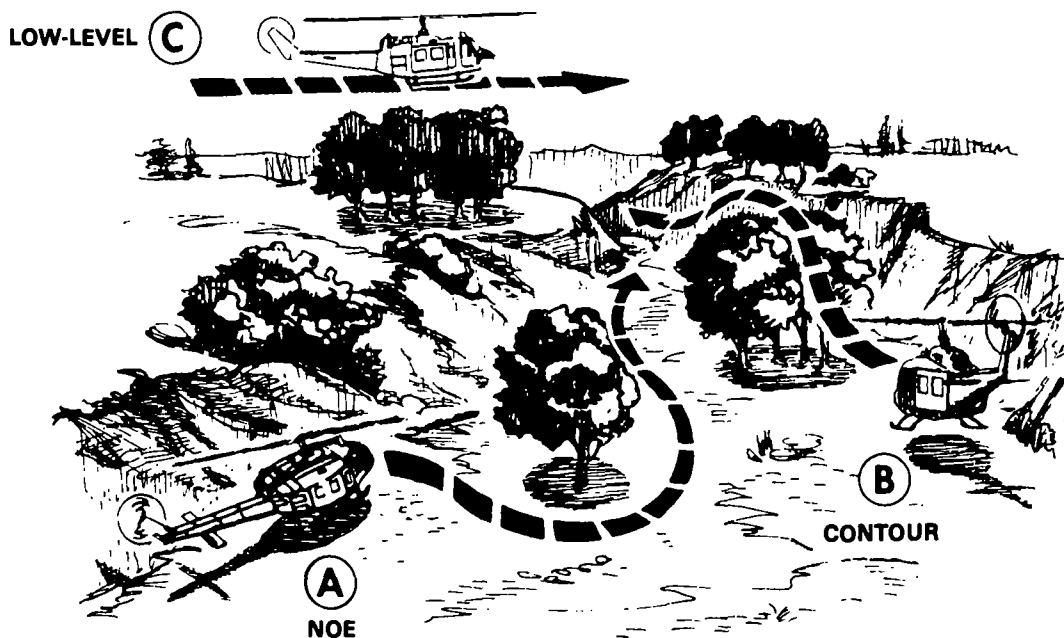


FIGURE 5-2. TECHNIQUES OF TERRAIN FLYING.

altitude where detection by a Threat force is avoided or minimized. It is usually performed at a constant indicated altitude and airspeed.

NOTE: When performing terrain flight, seldom will you ever perform pure NOE or contour flight. Due to variations in terrain and vegetation, you will transition from one terrain flight technique to another while maneuvering over the desired flight route.

SELECTION OF A TERRAIN FLIGHT TECHNIQUE

The illustration and definitions provide a specific answer to the question: "What is terrain flying?" However, the answer is not complete, because it is important to know when each terrain flight technique is used and why it is being used. The Threat profile (fig 5-3) provides a graphic description of

when you would use each terrain flight technique by comparing the terrain flight regimes to the Threat. To answer "why," the figure (fig 5-4) describing the survival probabilities portrays the changes of survival in the various regimes of flight against specific weapons systems.

Before any mission is flown, you must know what portion of the route will be flown at low-level, contour, or NOE altitudes, or a combination of these techniques. The decision as to which terrain flight technique will be flown is influenced by two factors.

□ *Threat.* When flying within the battle areas, threat weapons are capable of detecting and engaging your aircraft at very low altitudes. When operating within the range and altitude capabilities of Threat weapons, NOE and contour flight should be flown to avoid or minimize detection by Threat forces. Low-level flight may be performed where the aircraft is beyond or

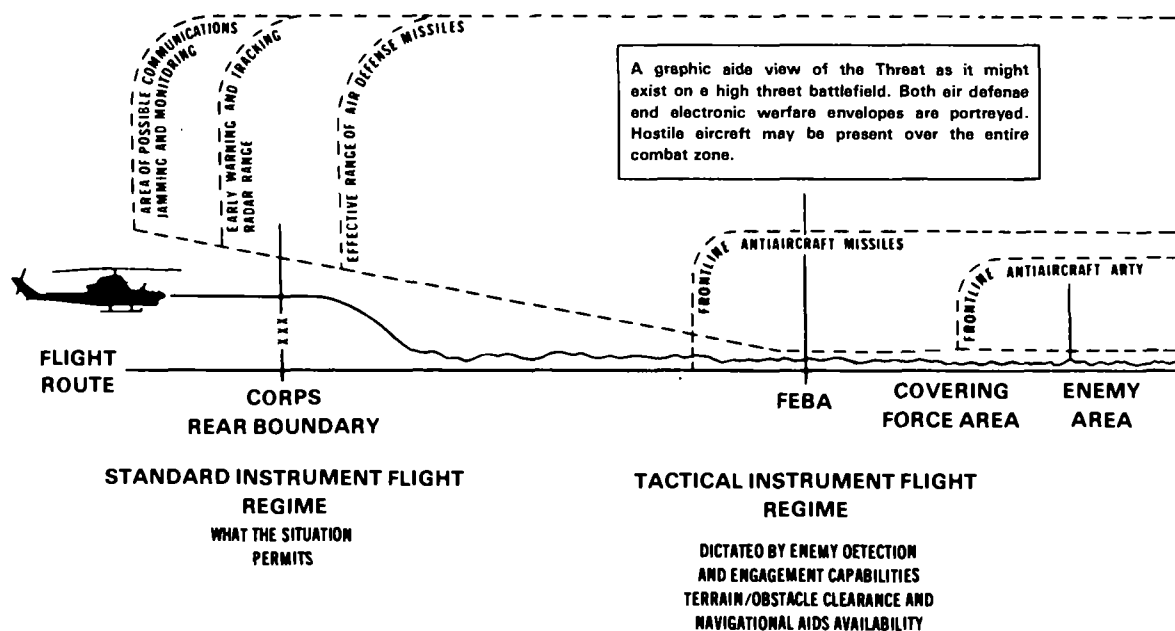


FIGURE 5-3. THREAT PROFILE.

below the engagement limitations of threat weapons.

☐ *Terrain.* The capability of threat weapons to detect an aircraft is significantly degraded by vegetation and terrain features which mask the aircraft from visual and electronic detection. The maximum safe altitude that can be flown is determined by the availability of terrain features and vegetation to mask the aircraft.

NOTE: The highest terrain flight altitude for the specific condition should always be used. Flight at high altitude reduces the difficulty of navigation, enables you to fly at a higher airspeed, reduces the hazards to terrain flight, and minimizes fatigue.

THE CHOICE OF WHETHER LOW-LEVEL, CONTOUR, OR NOE FLIGHT WILL BE USED AT A SPECIFIC TIME AND PLACE IS DETERMINED BY THE THREAT AND TERRAIN.

HUMAN FACTORS

Because of the precise flying and concentration required to accomplish terrain flying, it is extremely fatiguing. Fatigue is a difficult problem to cope with because it cannot be measured and often goes unrecognized by the individual or his supervisor. It can only be averted by minimizing the physical, emotional, and self-imposed stresses that produce fatigue. A few of the common stresses are prolonged flight, temperature extremes, sickness, flicker vertigo, poor eating

DO YOU SURVIVE AGAINST THESE WEAPONS...			FLYING THIS WAY?
NO 	NO 	NO 	
MAYBE 	MAYBE 	MAYBE 	
YES 	YES 	YES 	
ELECTRONIC DETECTION	OPTICAL DETECTION	VISUAL DETECTION	

FIGURE 5-4. THREAT AVOIDANCE TECHNIQUES.

habits, overweight, alcohol and tobacco indulgence, and personal problems. The most common signs of fatigue are deterioration of performance and judgment, causing poor coordination, daydreaming, object fixation, and slowed reaction time. Some of the ways to minimize fatigue in both training and combat environments include—

☐ *Establishing flight time limitations and crew rest periods.* It is important that you recognize fatigue and be able to admit being too tired to function safely. In combat, 140 flight hours per a 30-day period are considered the maximum that should be flown when flying at altitude. It is likely that these limits will have to be reduced in those units which habitually conduct day and night terrain flight. Flight time limitations and crew rest periods should be established to minimize flight fatigue.

☐ *Conducting daily physical fitness training.* Physically fit people have an increased ability to endure physical and mental stress, control emotions, relax, and sleep soundly.

☐ *Developing effective teamwork between aircrewmembers.* Teamwork greatly reduces fatigue by division of duties and a reliance on the other individual. Teamwork is developed through repetition until a task becomes second nature.

VISUAL PERCEPTION

Maintaining obstacle clearance is critical when performing terrain flight, especially

for NOE and contour flight. Your peripheral vision is the key to maintaining obstacle clearance during the day. The use of peripheral vision is a process learned through experience by operating near obstacles. It allows you to see objects up to 110° each side of center without looking directly at the object. You must develop the ability to estimate how close the aircraft can be flown to an obstacle without hitting it. When hovering close to obstacles and it is difficult to accurately estimate clearance, you should have a crewmember dismount and ground guide the aircraft over, under, or around an obstacle.

When terrain flying, visual search is required for accurate navigation and object recognition. Visual search is the ability to identify reference points in your field of vision. Both central and peripheral vision is used when performing visual search. To conduct visual search, the individual must first have some concept of what is to be seen. To aid in rapid recognition, you must have a visualization of the route and any weapons that may be encountered during the flight. In addition, you must have an understanding of how light shadows and seasons change the appearance of the terrain. A 4-hour change in time of day or a 10-degree change in direction of approach can alter visual expectation. With this knowledge, you can effectively use your peripheral vision to scan for forms that come close to the expectation. Each form is accepted or rejected peripherally, and your central vision makes positive identification. The probability of detecting and identifying a terrain feature or object will be determined by its size and the distance it is from the observer.

SECTION II

TERRAIN FLIGHT OPERATIONS

TERRAIN FLYING LIMITATIONS

Terrain flying imposes additional factors on the aviator and unit that may not be encountered on missions flown at higher altitudes. Because these factors impact on mission planning (fig 5-5) and execution, it is essential that you understand them. These factors with their associated problems and ways to minimize or solve them are described below.



FIGURE 5-5. MISSION PLANNING.

The line-of-sight radios currently available are restricted by mountainous terrain; and in certain cases, it will be impossible to maintain contact with a unit outside the immediate vicinity of the aircraft. To operate around the limitations of the system, you should identify those areas where best radio transmission can be

received. The construction of a terrain profile diagram will assist in identifying these areas. During certain operations, the commander may choose to assign aircraft, pathfinders, or retransmission equipment for radio relay purposes.

TERRAIN AND ENEMY ELECTRONIC WARFARE RESTRICT COMMUNICATION.

In addition to the restrictions imposed by the terrain, it will often be necessary to limit communications due to the ability of the enemy to electronically locate the aircraft from radio transmissions. Radio communications should always be limited to the absolute minimum. Operating under radio silence will be very common. Therefore, alternate communication procedures must be developed (fig 5-6). Light signals and nonelectronic communication cards may be used for communication between aircraft and ground elements. Marker panels, smoke canisters, and light signals can be used for communication between ground elements and the aircraft. To prevent confusion, all signals used should be standardized. The effects of the lack of communication can be minimized with detailed planning.

ALTERNATE COMMUNICATION SIGNALS SHOULD BE STANDARDIZED.

When terrain flying, the lack of communication causes a significant change in the procedures for control of a tactical opera-

tion. This affects both the ground and aviation commander. The ground commander will no longer be able to use an aircraft to supervise the activities of several units simultaneously from altitude. Typically, aircraft communications will only be a supplement to the ground communications network. When communications are not limited (fig 5-7), it is possible for the aviation commander to operate a centralized control system. However, when conducting terrain flying, control procedures will have to be tailored to the specific situation.

CONTROL MUST COME FROM WITHIN A UNIT, NOT FROM A COMMANDER CIRCLING HIGH OVERHEAD.

When terrain flying, control will often be the responsibility of the platoon, section, or team leader. Either of these must be able to execute the mission as planned and, equally important, they must be able to make sound tactical judgments when the plan must be modified while en route.

It is important that aviation missions be coordinated with friendly air defense artillery (ADA) units. You should be especially cognizant of the location of ADA units; know ADA unit criteria for identifying and engaging targets (visual recognition based on size, shape, markings, and color); and insure that onboard identification equipment (identification friend or foe (radar) (IFF)) is functioning and properly coded.

AIRCRAFT RECOGNITION PROCEDURES ARE ESSENTIAL.



FIGURE 5-6.

VISUAL SIGNALING TECHNIQUES.

When a unit is habitually conducting terrain flight, the commander should expect and plan for increased maintenance requirements. Blade strikes will probably increase and skin punctures will be more common. The higher power settings required for NOE flight impose a heavy strain on aircraft dynamic components—engines, blades, and transmissions—that could result in reduced mean time between

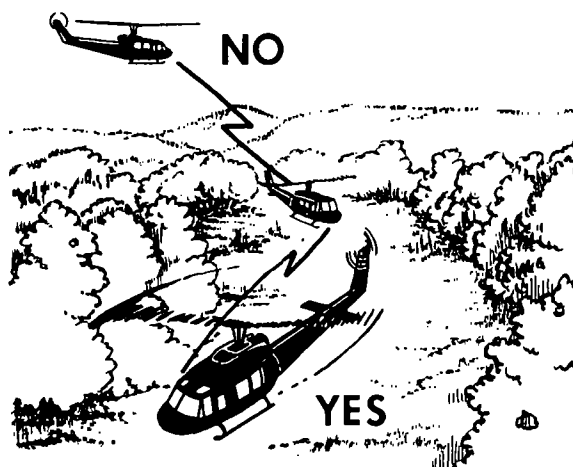


FIGURE 5-7. COMMUNICATION LIMITATION.

failure. Another important maintenance consideration is the attention that must be given to maintaining the windscreen in a clean and scratch-free condition. In a combat situation, maintenance teams will be required to perform in the field maintenance when aircraft are operating out of forward positions removed from unit maintenance facilities.

MULTI-HELICOPTER OPERATIONS

When operating in a high threat environment, a formation's specific shape is defined by the terrain, the tactical situation, the desired degree of control, and the terrain flight technique being flown. When performing NOE or contour flight, a staggered trail formation may be used. Trailing aircraft will employ free cruise as necessary to take advantage of concealment offered by the terrain and vegetation. When low-level flight is used, less separation is maintained and formation flexibility is possible. Each aircrew in the flight is responsible for the accuracy of navigation. It must be prepared to take the lead at any time and proceed to the destination. Visual signals, code radio transmissions, and secure radio should be used to assist in radio communications security.

When terrain flying, the greater the number of aircraft in a flight, the more easily they can be detected. In addition, a large group requires more terrain relief to remain concealed than does a small group. When a large number of aircraft are required to accomplish the mission, dispersion can be achieved by using numerous routes into an area with small flights of

aircraft using each route. However, it will often be necessary to use a single route in order to concentrate friendly suppressive fires.

When using NOE flight, individual aircraft within the flight moves as do individual infantrymen in a squad. The squad leader picks the general direction of travel, but each infantryman picks his terrain and moves by rushes or bounds within the loose formation. He is not required to step in the footprints of every man ahead of him. Likewise, aircrews pick their own terrain, moving by bounds independently from point to point within the formation. The pilot must be particularly careful not to maintain equal distances from preceding aircraft or exact flight routes which can aid enemy gunners. Each aircrew must be aware of the situation, the terrain, and the mission, and not follow blindly the tailpipe of the aircraft ahead.

If the flight is detected by hostile aircraft during multi-helicopter operations, disperse immediately. Each aircrew should be briefed on the dispersing and regrouping procedure during the preflight briefing. Refer to FM 1-2 for individual aircrew defensive measures against attack by hostile aircraft.

**IF ATTACKED BY HOSTILE AIRCRAFT
OR THE RADAR DETECTOR INDICATES
THE AIRCRAFT IS BEING ENGAGED:**

- **DISPERSE IMMEDIATELY!**
- **PROCEED WITH EACH AIRCRAFT
MAINTAINING ITS OWN CON-
CEALMENT.**
- **REGROUP WHEN CLEAR.**

Three methods of movement that are used when conducting multi-helicopter operations are traveling, traveling overwatch, and bounding overwatch.

□ *Traveling* is primarily used where contact is *not* likely such as in corps and division rear areas. Low-level and contour flight will be used when movement is made using the traveling technique (fig 5-8). It is the fastest method for moving a flight of aircraft; however, it provides the least amount of security. If the mission is conducted in an area where contact is possible, the flight should be preceded by a

single aircraft that acts as pointman for the flight. High airspeeds are flown when using the traveling technique.

□ *Traveling overwatch* is used when contact is possible (fig 5-9). It is characterized by continuous movement of the main elements (during an air assault operation, the lift platoons). The overwatch elements (the gunships) move at variable speeds and may even pause for short periods if necessary. The overwatching element keys its movements to the terrain and its distance from the main element. Normally, the range at which targets can

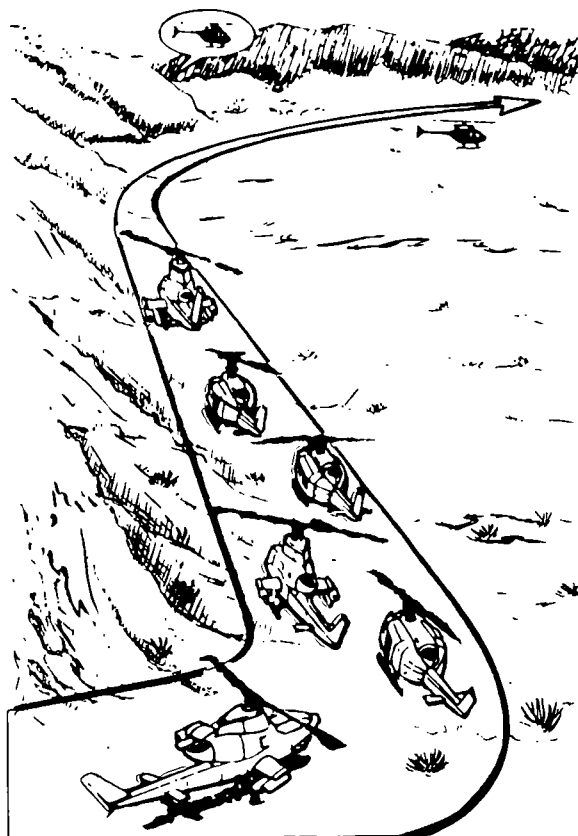


FIGURE 5-8. MULTI-HELICOPTER MOVEMENT (TRAVELING).

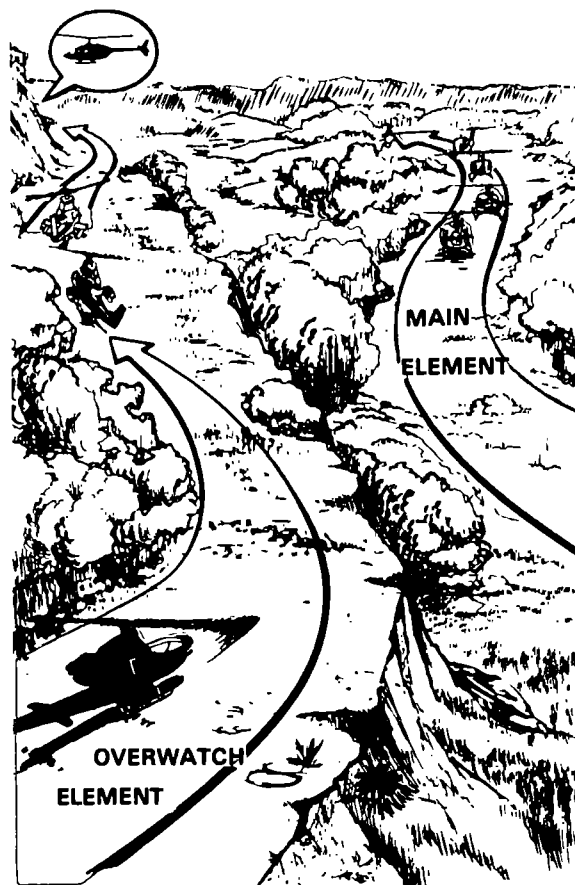


FIGURE 5-9. MULTI-HELICOPTER MOVEMENT (TRAVELING OVERWATCH).

be observed will be close. Therefore, the overwatch element will remain well within the effective ranges of its weapons systems and is always prepared to fire or maneuver, or both, to support the main elements. Contour flight altitudes are the normal terrain flight techniques used when employing the traveling overwatch tactic. Airspeed is generally high and will vary as influenced by the weather, ambient light, and the threat.

□ *Bounding overwatch* is used when contact is possible and the greatest degree

of concealment is required (fig 5-10). Elements move by bounds with one element in position to fire or maneuver before the other element moves. Once in position, the bounding element becomes the overwatching element and vice versa. Airspeed during each bound will vary depending on the availability of vegetation and terrain features for concealment. Movement of the flight to its destination will be slower than the other movement techniques. Both contour and NOE flight are used to perform bounding overwatch.

TERRAIN FLIGHT PLANNING

The requirement for accurate intelligence data—mission, enemy situation, terrain and weather, troops available, time, and space (METTS)—is essential to planning. During highly fluid situations, intelligence information can change rapidly. This requires that field reports be constantly evaluated, especially as they affect previous intelligence information related to the ability of the enemy to detect and engage an aircraft.

ACCURATE AND CURRENT INTELLIGENCE DATA IS ESSENTIAL FOR TERRAIN FLIGHT PLANNING.

Following the operations (G3/S3) and intelligence (G2/S2) briefing, you should plot the selected landing zones, ambush and/or firing positions, aircraft control points, and known or suspected enemy positions. You will then select possible flight routes and alternate routes if not given in the mission briefing. The routes are then carefully studied to determine



FIGURE 5-10. MULTI-HELICOPTER MOVEMENT (BOUNDING OVERWATCH).

their susceptibility to visual or electronic detection by Threat weapons systems. Altitude restrictions based on the threat analysis are then determined and marked on the map. The terrain in the immediate vicinity of the routes should be evaluated for potentially hazardous areas. Hazards along the route should be marked on the map. Key terrain features should be identified and highlighted to aid in rapid recognition. After performing the map reconnaissance, you should be able to visualize the entire route of flight. Current aerial photographs of the area should be used during the map reconnaissance to insure map accuracy and to check for hazards.

**THOROUGH MAP STUDY AND
THREAT ANALYSIS ARE ESSENTIAL
FOR MISSION SUCCESS.**

When planning for terrain flight, you must consider detection avoidance. Unfortunately, the terrain does not always lend itself to your advantage for conducting terrain flight. There will be times when detection must be expected. When these conditions exist, suppression of threat weapons must be planned. Before employing suppressive fires, consideration must be given to the tactical advantage that is gained by using passive countermeasures—terrain flight and aircraft survivability equipment (ASE)—to avoid detection.

**OPERATIONAL CHECKS OF THE AIR-
CRAFT SURVIVABILITY EQUIPMENT
MUST BE PERFORMED PRIOR TO
TAKEOFF.**

Whereas thorough planning and training are the keys to mission success, preplanning is the key to rapid response. Unit commanders must anticipate *what* may be required of aviation assets and *where* they may be needed. Mission planning must start early, even before a mission is received. Planning includes a detailed map reconnaissance of likely areas of operation to determine possible routes of flight, landing zones, arming and refueling points, and the other elements essential for rapid reaction. To insure that current and future ground and air tactical operations are coordinated, Army aviation personnel must work closely with the planning staff of the ground commander.

**FLEXIBILITY WILL BE IN DIRECT
PROPORTION TO PREPLANNING.**

ROUTE PLANNING CONSIDERATIONS

The first consideration in route planning is to know the location of Threat weapons systems. Routes can thus be planned to keep the highest possible terrain and/or thickest vegetation *between* the Threat and the aircraft. When operating in the mountainous or rolling terrain, plan the flight route along the friendly side and below the crest of a ridgeline. In very gently rolling terrain, plan the route across the low terrain such as streambeds where it does not serve as an avenue of approach to the enemy position. In arid or open areas, plan the route along streambeds or depressions where trees may exist. Threat weapons systems will have difficulty operating in rugged, swampy, and heavy

vegetated terrain. Routes should be planned in areas that are inaccessible to ground vehicles. When feasible, routes should avoid population concentrations due to the large number of hazards and the adverse effect of lights on night vision. Routes should not follow manmade linear features such as roads, canals, or pipelines, unless required due to restricted visibility. These linear features normally do not follow a course which offers the greatest masking opportunity. Avoid flights over large bodies of water. No protection from visual or electronic detection is afforded when flying over open water. To the maximum extent possible, routes should be planned over heavily vegetated areas as opposed to open terrain. This is especially true near enemy positions, because the vegetation restricts the ability of the enemy to visually detect the aircraft. Also, by flying over vegetation, the aircraft shadow, which is the primary means by which high-performance aircraft visually locate low flying helicopters, can be broken and lost in the darker vegetation. Ridge-lines should be crossed at low points so as to minimize exposure and reduce exposure time. Some terrain features may provide good masking; however, aircraft movement is restricted. Such terrain features as deep river valleys or gorges should be avoided.

Checkpoints used along a route should be terrain features in preference to manmade objects. This is because manmade features are subject to change or destruction and unplotted features may be confused for intended checkpoints. When manmade objects are used, they should be used primarily to help confirm the identity of terrain features.

Easily identifiable terrain features must be selected for checkpoints at night due to poor visual acuity. Size, shape, and contrast are factors that must be considered in selecting a checkpoint along a route at night.

The terrain flight altitude that will be flown is based upon the degree of masking that can be achieved from the terrain and vegetation located along the route. When operating beyond the range of enemy air defense weapons, but within range of enemy surveillance equipment, route selection is not the most important factor affecting the flight altitude. In these areas, altitude is determined based on the limitations imposed by friendly forces such as airspace management for aircraft, artillery, and air defense weapons. Friendly tactical considerations also include counterintelligence considerations. For example, altitude should be below enemy surveillance capability in the vicinity of command posts, assembly areas, and forward arming and refueling points (FARP), to prevent enemy radar from locating these positions because of the high density of traffic in the areas.

When selecting a route, consideration must be given to the prevailing meteorological conditions that exist along the route. During certain times of the year and day, weather restrictions may prohibit visual flight conditions. When poor weather conditions are known or forecasted for a specific area and time, plan the route to avoid this area.

Primary and alternate routes into and out of the objective area should be planned. This is necessary to protect against an

enemy tactic to emplace weapons along the approach route in anticipation that the helicopter will return along the same route. Alternate routes are also used in the event the tactical situation restricts use of the primary route.

Route planning can only be as good as the map is accurate. In some cases, the only map available will be out of date and the contour interval is too large. Therefore, changes to the route, based on observation of the actual terrain, should be made if necessary to remain masked.

In summary, route planning considerations are:

☐ Avoid flight away from known or suspected Threat air defense weapons and ground units.

☐ Keep a terrain mass and/or vegetation between the enemy and the aircraft.

☐ Avoid built-up areas.

☐ Avoid using manmade objects as primary checkpoints.

☐ Avoid areas where there is a high density of obstructions.

☐ Do not follow manmade linear features.

☐ Avoid silhouetting the aircraft when crossing ridgelines.

☐ Plan primary and alternate routes.

☐ Select route where recognizable terrain features are located.

☐ Avoid open areas and large bodies of water where terrain permits.

☐ Determine altitude restrictions based on threat, masking offered by the terrain, and friendly tactical considerations.

☐ Be prepared to make inflight changes to take advantage of better masking conditions.

☐ Avoid an area where meteorological conditions are a hindrance to mission accomplishment.

☐ Plan routes over terrain that is inaccessible to wheeled or tracked vehicles.

MAPS AND AERIAL PHOTO PREPARATION

Certain essential items must be placed on the face of the map. Depending on the type mission, a portion of the following information should be marked on the map:

☐ *Air control point (ACP).* An air control point is an easily identifiable point and provides positive control and coordination during an airmovement. These points define the intended flight route. ACPs may be marked with a circle around the feature. This should be in transparent ink so as not to obscure any feature.

☐ *Course lines.* A pencil line should be drawn to denote the desired ground track. Course lines should be indicated as sharp, clear lines on the map.

☐ *Magnetic headings.* Magnetic headings are shown to provide general heading for each leg. Grid magnetic angle must be applied to the course to obtain a magnetic heading.

☐ *Mileage tic marks.* Mileage tic marks are pencil marks drawn to bisect the course line at 3,000-meter intervals. These marks assist in range estimation while traveling along the course.

☐ *Time tic marks.* Time tic marks are pencil marks drawn to bisect the course line at approximately 2-minute intervals. Distance between the time tic marks will be dependent upon the operating airspeed. The time tic marks assist in dead-reckoning navigation when identifiable terrain features are not available.

☐ *Checkpoint.* A checkpoint is a landmark that is selected along or adjacent to the flight route and used to fix an aircraft's position. A checkpoint must be a unique feature or group of features in a given area.

☐ *Miscellaneous.* Other items of information that may be placed on the map face are distances, barriers, and obstacles. However, this information may clutter the map and serve only to confuse the aviator.

☐ *Highlighting and shading.* At night it is difficult to identify contour lines. Highlighting of prominent contour lines with a pencil or pen helps in identification of terrain features. Also, the shading of prominent areas of foliage helps identify specific areas of concern.

☐ *Aerial photo.* An aerial photo supplements the terrain information found on a tactical map. A detailed study of an aerial photo may reveal terrain features which will provide a good checkpoint that could not be identified from the map. Because the photo is current, information relating to manmade features will be more accurate. Changes such as a new road, additional

cultivated land, or a new bridge may confuse you; however, prior knowledge of these changes will significantly aid in navigation. Obstacles, whether natural or passive defensive measures, can be detected and will assist in route selection. The aerial photo normally is not used as the primary reference for navigation during the conduct of the flight. Information acquired from the photo which will assist in navigation or obstacle recognition should be transferred to the map. In a situation where the accuracy of the map detracts from your ability to navigate, the aerial photo may be used as the primary reference for navigation.

☐ *Folding map.* The need for detailed information requires that a large-scale map (1:50,000 or larger) must be used for terrain flight navigation. Because of its bulky size, it must be folded. A technique must be used which will allow the navigator to follow the helicopter's position along the ground while transferring from one fold to another.

CAUTION: Maps marked with classified information become classified and must be handled and stored in accordance with the procedures outlined in the appropriate regulation.

PERFORMING TERRAIN FLIGHT

The manner in which the pilot performs terrain flying is directly influenced by the mission. The scout who is searching for the enemy will use NOE extensively. He will sneak and peak, dash across open fields, and use many other techniques which the cargo pilot will seldom, if ever, use. Even with the differences in the way terrain

flying will be conducted for any given mission, there are fundamental elements necessary to successfully conduct terrain flight.

CREW INTEGRATION

Terrain flying is a crew activity conducted by at least two qualified aviators or an aviator and a qualified aeroscout observer.

Prior to the execution of either a day or night mission requiring terrain flight, each crewmember should know and understand the duties which must be performed while in flight. The ability of the aircrew to perform as an effective team is dependent upon the amount of individual and crew training that has been received. Detailed premission planning and ground rehearsal will also help improve the coordination that is essential during the conduct of the mission. Some of the responsibilities for each crewmember are as follows:

☐ *Pilot.*

- Fly the aircraft (hazard and obstacle avoidance).

- Assist in navigation by pointing out significant features to the copilot/navigator.

- Follow navigational instructions issued by the copilot/navigator.

- Monitor radios and make radio calls, as appropriate.

- Designate specific crew duties.

☐ *Copilot.*

- Navigation. (Know the location of the aircraft at all times.)

- Assist the pilot in hazard and obstacle avoidance by telling him what to expect ahead.

- Give navigational instructions to the pilot (using rally terms).

- Monitor aircraft heading.

- Monitor aircraft performance gages.

- Monitor radios and make radio calls, as appropriate.

☐ *Flight Engineer/Gunner.*

- Monitor the mechanical condition of the aircraft.

- Assist in navigation by pointing out significant features to the copilot/navigator.

- Observe for obstacle and hazard clearance during hovering and landing operations.

- Perform any other specific tasks directed by the pilot.

**TERRAIN FLIGHT IS A CREW ACTIVITY.
IT CAN ONLY BE PERFORMED SUCCESSFULLY WITH TEAMWORK!**

PRETAKEOFF STANDING OPERATING PROCEDURE (SOP)

In addition to identifying specific aircrew duties, a pretakeoff SOP should be established which identifies the responsibilities and procedures for both the aircrew and passengers. The following factors should be included:

☐ *Briefing.* A thorough briefing should be given prior to the execution of any mission requiring terrain flight. The following items are considered essential:

- Lost communication procedures.
- Downed aircraft procedures.
- Helicopter instrument flight rules (IFR) breakup and recovery plan.
- Procedures for recovery from terrain flight when adverse weather conditions—high winds, low visibility—are encountered.
- Procedures for reporting new or unforeseen hazards on the terrain flight course.

☐ *Mission-essential equipment.* In addition to the required life support equipment and aircraft survivability equipment, aircrews must insure that other equipment such as local area maps, communication-electronics operating instructions (CEOI), a -10 Operator's Manual, visual communication devices, and, for night operations, such items as flashlight and night vision devices, are on board the aircraft.

NOTE: Aircrew personnel should receive training on both life support and aircraft survivability equipment prior to performing a mission that may require use of the equipment.

☐ *Power checks.* Engine health indicator tests should be conducted in accordance with appropriate aircraft engine health indicator test logbook checklist. A power check will be conducted prior to each takeoff. The procedures for performing a power check are outlined in the Operator's Manual (-10). A more detailed explanation of how to perform a power check is contained within appendix E.

☐ *Safety precautions.* Smoking by either the crew or passengers when conducting terrain flying is not allowed. Under most conditions, the clear visor should be in the down position during flight. The visors must be clean and free of scratches. Armor plates should be in the forward position. During terrain flight training, all personnel will be seated and restrained by safety belts.

☐ *Inflight emergency procedures.* Due to the short reaction time to an inflight emergency, each member of the crew should know what his responsibility is in the event of an emergency. An attempt to transfer controls should not be made. The crewmember not flying will make the emergency radio calls while the crewmember at the controls flies the aircraft.

NAVIGATION

An aviator who has navigated successfully at altitude may feel that these skills can be transferred to accomplish navigation at terrain flight altitudes. This unfortunately is not true.

TO SUCCESSFULLY NAVIGATE, THE AVIATOR MUST BE ABLE TO VISUALIZE THE ACTUAL TERRAIN AS DEPICTED ON A MAP.

Terrain flight navigation is difficult because the flat visual angle distorts shapes compared to the map and because vertical relief is the primary means of identifying checkpoints. To navigate accurately, you must be proficient in map interpretation and terrain analysis skills. Additionally, you must be able to visualize from the map how the terrain should appear. You must be able to look at the terrain and identify the position on the map. Navigation is more difficult when flying at NOE altitudes. This is due to the limited visual viewing area. Low-level navigation is easier because at the higher altitudes associated with low-level flight the visual viewing area is larger. This enables you to more accurately identify terrain and manmade objects by shapes which are depicted directly on the map.

Terrain flight navigation requires an exchange of information between the crewmembers. The crewman navigating furnishes the pilot with the information that is required to remain on course. Rally terms such as turn left, stop turn, increase airspeed, are used by the navigator to

convey instruction to the pilot. To assist the navigator, the pilot points out approaching terrain features. Standardized terms should be agreed upon to identify terrain features, because terrain features are often identified by different names in various parts of the country. For example, a body of water called a creek in some parts of the country might be referred to as a stream or brook in other areas. Standardized terms will help prevent misinterpretation of information and reduce unnecessary cockpit conversation.

Certain aspects of terrain flight navigation differ depending on whether low-level, contour, or NOE flight is being performed. Because terrain flying normally will involve a combination of these flight techniques during any given flight, you must be familiar with the navigational techniques associated with all three. Navigational techniques that are applicable to NOE and contour flight include:

□ A technique used to aid in terrain flight navigation is to identify a prominent terrain or manmade feature some distance ahead of the aircraft that lies along or near the course. Using this point to key on, the pilot can maneuver the aircraft so as to take advantage of the best terrain and vegetation to achieve concealment while advancing along the general axis of movement. The ground track may deviate from the preselected course; however, upon reaching the recognizable feature the aircraft should be on the preselected course or using another distant terrain feature as an aid to navigation. When in close proximity to the objective, you must return to the preselected course and use precise navigation.

□ During the execution of a mission requiring that terrain flight be performed, you may find that the preselected course does not provide the good concealment for the aircraft from Threat forces. Upon encountering this situation, you should change the course so as to follow a route that will avoid or minimize detection of the aircraft. The distance you must deviate from the preselected course will vary depending on the nature of the terrain and availability of vegetation; however, you should return to the preselected course where terrain masking is available.

□ While en route to the objective, a condition may be encountered—Threat weapon, artillery fire, weather—which prevents you from following the preselected flight route. Upon encountering this situation, you must immediately react by maneuvering the aircraft away from the area which is a threat to safe flight. Because an immediate response is required, there will be little time to plan a new route. The pilot must pick a course that provides the best concealment and that is oriented along the general axis of advancement. The navigator must follow the flightpath on the map. When performing responsive navigation, the pilot must assist the navigator by providing information that will aid in navigation. As the flight progresses, the navigator must begin to plan ahead until such time as the pilot is following a course selected by the navigator.

□ When performing NOE flight and none of the general navigational techniques apply, the pilot must follow the desired route by identifying a series of successive checkpoints. To remain continuously oriented, the navigator must identify the

terrain features depicted along the route with the actual terrain feature. This requires that he be highly proficient in map interpretation and terrain analysis and that he and the pilot work together as a team. Specific techniques for providing the pilot NOE navigation instructions are discussed below:

- When possible, the pilot should follow an identifiable terrain feature such as a streambed, draw, or spur.

- Guidance information should be provided by the navigator in small increments. Generally, it need not be provided beyond the next turning point (fig 5-11). A turning point is a point where the route makes a major change in direction. To prevent confusion, several terrain features should be used to identify a turning point.

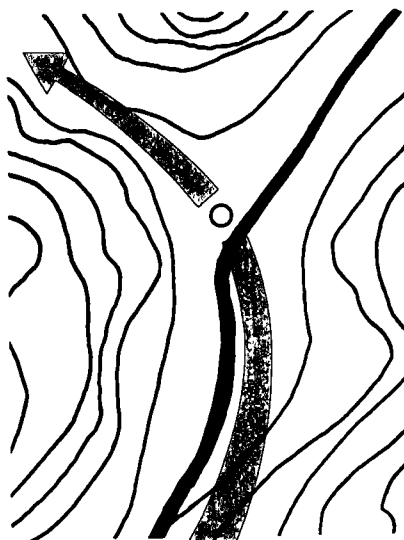


FIGURE 5-11. A TURNING POINT.

- Heading information should be provided in such a manner that the pilot

does not have to focus his attention inside the cockpit. He should be told to turn to a "clock" position or recognizable terrain feature.

- The pilot should not be told to fly a specific airspeed, because this requires him to look inside the cockpit. He should be told to increase or decrease airspeed.

□ Whereas NOE navigation requires precise following of a well-defined route, contour navigation is less precise because the contour route is more direct. Since the contour route is planned to utilize the terrain to achieve concealment, it must be followed closely. Due to the more constant and generally high airspeed which characterizes contour flight, checkpoints on the route will be located further apart.

□ Aircrew teamwork is also essential for contour flight. The pilot must focus his attention outside the aircraft and not be required to use the instruments to follow navigation instructions. The most effective technique for providing navigation instruction is to combine the use of terrain features and rally terms. The crewmember navigating provides the pilot with airspeed information so that checkpoints are crossed on schedule.

□ Many of the techniques relating to NOE and contour navigation are applicable for low-level navigation. However, several techniques can be used for low-level navigation which cannot be used for contour or NOE navigation. Computed time-distance can be used effectively for low-level navigation, since low-level flight is characterized by constant airspeed and the course line can be accurately measured.

The pilot can be told to fly specific headings and airspeeds since he has increased reaction time and obstacle clearance. Also, radio navigation may be used to achieve accurate navigation; however, this is dependent on the terrain and enemy situation.

AIRCRAFT HANDLING

To perform terrain flying safely, you must maneuver the aircraft using precise flying techniques. When terrain flying, aircraft control is more critical than when flying at altitude, because the aircraft is flown closer to the terrain and hazards (fig 5-12). This requires that you be aware of the dimensions of the aircraft and the time it requires for the aircraft to react to control input.



FIGURE 5-12. HAZARDS OF NOE FLIGHT.

The lift capability of the aircraft is dependent to a great extent upon your ability to maneuver the aircraft using small control inputs. It is a normal tendency to be tense when maneuvering close to an obstacle at slow airspeeds. Through training and self-control, the aircraft can be flown with precision even when required to perform the most demanding mission. When operating in a terrain flight environ-

ment, more power is required to perform the normal maneuvers. To insure the aircraft is operating within the design limitations, you must know the procedure for determining if sufficient torque for the gross weight of the aircraft is available to perform the mission. A comprehensive knowledge of the -10 performance chart with strict adherence to the operating limitations is required.

Aircraft handling also involves your ability to judge obstacle clearance. You must be able to quickly and accurately decide when to go over obstacles rather than between or under them. Also, you must know how to use vegetation and shadows to reduce glare.

The specific flight maneuvers required to perform low-level and contour flight will differ. This is due to the difference in the height above obstacles and the airspeed for the different modes of terrain flight. For example, to stop abruptly when at NOE altitude (a quick stop), the aircraft must pivot around the tail rotor's horizontal plane (fig 5-13). This requires that col-

lective pitch be increased prior to beginning the deceleration, so that the nose comes up and the tail doesn't drop. The amount of pitch applied is dependent upon forward airspeed, the load, and how fast the maneuver is performed. To stop when conducting low-level flight, a normal deceleration is performed.

EMERGENCY SITUATIONS WHEN TERRAIN FLYING REQUIRES INSTINCTIVE REACTIONS.

Emergency procedures are more critical when performed at terrain flight altitude. Most aviators need additional training to satisfactorily cope with emergency situations associated with terrain flying. Emphasis must be placed on training aircrews to perform maneuvers that are most critical when performed at terrain flight altitude. Such maneuvers are low-level autorotations, low side governor failure, loss of antitorque thrust.

Although the majority of the tactical missions flown by Army aircrews will

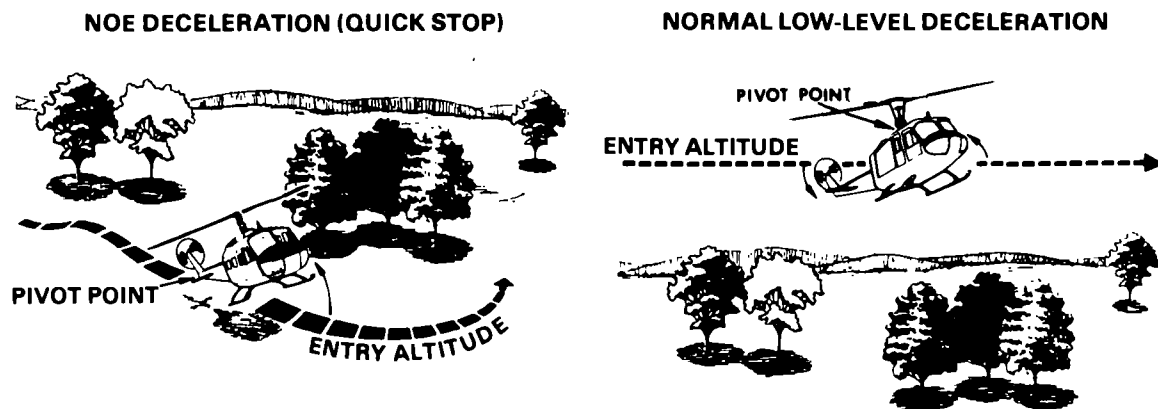


FIGURE 5-13. NOE QUICK STOP.

involve carrying cargo internally, there will be requirements to transport cargo externally at terrain flight altitudes. To avoid detection when carrying an external load, it is essential that the aircraft be flown as low as conditions will safely allow. Maneuverability will be limited due to aerodynamic load instability. Pilot overcontrol will further aggravate oscillation of the external load. Aircraft control is the key to operating with an external load at low altitudes. Maneuvers must be performed slower with small control inputs. Also, the aircraft should be flown at slower airspeeds. Aircrew coordination is essential to insure clearance between the load and any obstruction. The use of a short sling allows the aircraft to be flown at a lower altitude and reduces oscillation. The decision to release the load when an unsafe condition develops must be made quickly to avoid total destruction of the aircraft.

DETECTION AVOIDANCE TECHNIQUES

The rules for detection avoidance will aid you in moving about the battlefield undetected, especially when searching for the enemy or when the location of Threat weapons is unknown. These rules are more applicable for a single helicopter or a small group, but may be employed when moving in a large group.

The cardinal rules for detection avoidance when moving about the battle area are:

☐ *Keep low and vary airspeed and course to remain masked.*

☐ *When crossing a ridgeline which may be exposed and cannot be bypassed, pick your way to the lowest crossing point, and dash down the forward slope to the closest available concealment.*

☐ *When crossing open flat areas, cross at the narrowest point and dash across. Try to keep vegetation between you and the enemy and follow low terrain. Remember, keep your exposure time to less than 10 seconds.*

☐ *When paralleling a vegetated area, fly below and near the vegetation.*

☐ *Fly as close to the ground as vegetation and manmade features will allow.*

☐ *Hover or land whenever necessary to reconnoiter an area prior to proceeding. If necessary, dismount! Look through or around vegetation rather than over it.*

☐ *When flying over dense vegetation, follow the lowest contours of the vegetation rather than the lowest contour of the earth.*

☐ *Do not fly into a situation where you have no room to maneuver if attacked.*

☐ *Always have an evasive maneuver planned if attacked.*

CAUTION: *Never turn your tail directly toward the enemy if any other choice exists.*

BATTLEFIELD FLIGHT SAFETY

On a battlefield, we cannot afford losses caused by accidents and carelessness. Safety must therefore be totally integrated with mission requirements when conducting terrain flight. Specific flight safety factors that must be considered are:

□ *Physical Hazards.* When conducting terrain flying during tactical operations or training, you must be aware of the wire hazards (fig 5-14) in the area of operations (fig 5-14). These hazards consist of powerlines, communications wire, TOW missile guidance wire, and wire barriers erected by the enemy. To minimize the danger of wire strikes, you should make a detailed study of the unit's hazard map prior to each flight. Any unmarked wires you detect during a flight should be plotted on the unit's hazard map. When communications wire is laid by aircraft, the route should be plotted on the hazards map. Areas in which large numbers of TOW missiles have been fired from aircraft should be identified.

The best means of coping with wires when conducting terrain flight is to know where they are and avoid them. To determine where wires may be located prior to the execution of a mission, you should conduct a map and aerial photo reconnaissance of the area of concern. The unit hazard map will also aid in detection of wires. When flying in an area where wire obstructions are unknown, the helicopter should be flown at a slower airspeed. Flight at slower airspeeds provides more time for detection of wire and evasive action to avoid contact with wires. Specific visual cues for locating wires are—

- Look for the swath through the vegetation.

- Spot supporting poles on aerial photos.

- Expect wires along roads, waterways, near towers, and in the vicinity of buildings.

THE AVIATOR MUST LEARN TO IDENTIFY THE VISUAL CUES TO WIRE LOCATION.

In addition to wires, there are other physical hazards such as trees and birds with which crewmembers must cope. Helicopters are particularly vulnerable to blade strikes at NOE altitudes. Therefore, you must insure obstacle clearance during flight and when using trees for masking and unmasking maneuvers. Also, a dead tree which is taller than the surrounding vegetation is difficult to see if attention is focused too far ahead of the aircraft. Damage may occur to the aircraft as a result of a bird strike. The extent of damage is determined by the size and number of birds and the airspeed of the aircraft upon contact. As a rule of thumb, you should not try to avoid birds unless they are in a very large flock. Generally they will avoid the aircraft. To protect against personal injury caused by tree branches, birds striking, or pieces of a broken windscreen, crewmembers should wear their visors down and insure that the armor plate on the seat is in position.

When terrain flying, *the most important factors in physical hazard avoidance is for the pilot to keep "his head out of the cockpit," and use proper visual scanning techniques.*



FIGURE 5-14. WIRE HAZARDS.

A HAZARDS MAP SHOWING HAZARDS WITHIN THE AREA OF OPERATION MUST BE MAINTAINED BY EACH UNIT AND UPDATED AFTER EACH FLIGHT WHEN AN UNPLOTTED HAZARD IS LOCATED.

☐ *Weather Hazards.* Weather can be a hazard if proper precautions are not taken. Any time visibility is reduced, altitude must be increased and/or airspeed decreased to provide the added reaction time required to avoid obstacles. Flight into the sun is very hazardous when it is low on the horizon and should be avoided whenever possible. In a combat situation, it will not always be possible to increase altitude because of enemy air defenses. Therefore, airspeed must be reduced to provide added reaction time. Also, thermals can be dangerous at terrain flight altitudes if you do not anticipate the loss of altitude. This is especially dangerous when terrain flying with external loads.

Wind conditions create an unsafe operating environment for terrain flight operations. Downwind flight at slow airspeeds requires more power, thus reducing the operating gross weight of the aircraft. Gusty winds affect the control of the aircraft and may cause inadvertent contact with an obstruction. The unit SOP should identify the limitations for windspeed and gust speed. The aircraft Operator's Manual (-10) gives recommended operating limitations for windspeeds and gust speed.

☐ *Maintenance.* Greater emphasis should be placed on postflight inspections, to include an inspection of the rotor blades, bottom fuselage, tail boom, and tail rotor for tree strike damage. The rotor head assembly and tail rotor should also be checked for evidence of wire strikes and accumulation of wire. Sufficient time must be allowed for the aircraft to be maintained in the best possible condition.

Windscreens must be cleaned to avoid any obstruction to visibility. Aircraft with windscreens that are scratched to the extent that they degrade vision or create a distraction should not be used when conducting terrain flying.

BECAUSE OF THE LOW ALTITUDES ASSOCIATED WITH TERRAIN FLYING, THERE IS ABSOLUTELY NO MARGIN FOR MAINTENANCE ERROR. ALSO, STRINGENT PREFLIGHT, POSTFLIGHT, AND PERIODIC INSPECTION STANDARDS ARE ESSENTIAL FOR SAFETY.

☐ *Wire Crossing Guidelines.* Wires are the major hazard to aircraft when terrain flying because they are difficult to see. Locating wires is the *entire* aircrew's responsibility. Once the wires are located, they can be crossed safely, using the following flight techniques:

• The safest way to cross wires is by overflying them at or near a pole. This is because the pole can be seen more easily and it provides a visual cue for estimating height above the wires.

- A second method is to cross the wires at the midpoint between the supporting poles. This is the lowest point of the wires. Difficulty will be experienced estimating the height of the wires. You can judge a safe crossing height by using the poles as a reference. If the aircraft is flown at the same altitude of the poles or above, it will clear the wires. Height estimation is also aided by crossing the wire at a reduced speed.

NOTE: Depending on the type and height of the poles, guy wires may be attached to the poles. You must begin the climb in time to avoid these guy wires; or if passing beneath the wires, sufficient lateral separation must be maintained to clear them.

In combat, it may be necessary to underfly wires to prevent exposing the aircraft to enemy visual or electronic detection. Flight between two wires or sets of wires should not be attempted. When the tactical situation requires that wires (or other manmade structures) be underflown, enough clearance must exist to provide for the height of the aircraft, the hover height, and a "margin for error."

CAUTION: The highest point of most helicopters is at the tip of the main rotor or the high point of the tail rotor arc. During forward hover, the height of the aircraft increases because the rotor disk displaces upward.

When underflying wires:

- Aircrewmembers will assist the pilot in estimating a safe clearance altitude.

- Airspeed should be no greater than hover speed (brisk walk).

- Cross near a pole because the wires are higher and the pole aids height estimation. However, insure lateral clearance from guy wires and poles.

- Use another aircraft or a dismounted crewmember as a guide if clearance is marginal.

- If it is suspected that a rotor blade has hit a wire, land and inspect for damage and wire entanglement.

NOTE: The aviation unit commander should coordinate with ground forces to insure new wires are marked for aerial identification where aircraft would frequently cross over the wires.

Minimum Clearance Between Ground and Wires—

OH-58	20 feet* + hover height
OH-6	17 feet* + hover height
UH-1	25 feet* + hover height
AH-1	25 feet* + hover height
CH-47	29 feet* + hover height

*Extreme aircraft height, aircraft on the ground, flight controls neutral plus a 10-foot margin for error.

To underfly wires safely, you must estimate accurately the clearance of the wires above the ground. In some cases, there is no doubt that the wires are high enough to insure clearance; in other cases, a judgment will be required. Therefore, it is important that you receive training in estimating clearance. This can be done by estimating the height of the wires at selected sites in the training area. The actual clearance should be known. Also, pictures showing wires with known clearance can be used for training in an academic environment.

CAUTION: Wire sag will increase with an increase in ambient temperature. Marginal clearance situations in the early morning hours may be inadequate in the afternoon.

TERRAIN FLYING IN ADVERSE WEATHER

The staying power of Army aviation units is increased significantly when aviators are trained so that they can perform terrain flying in adverse weather. This capability must be developed because during war Army aviation units must perform both day and night and in good and bad weather. The aviation unit commander must carefully weigh the mission requirements against the capabilities of the aircrews to perform terrain flight during adverse weather conditions.

Visibility and *ceiling* are two conditions of adverse weather that affect terrain flight (fig 5-15). Low ceiling and poor visibility degrade the enemy's capability to detect and engage aircraft with optical and infrared anti-aircraft weapons. A low

ceiling is an asset when operating in an area where enemy tactical air is a threat. Low ceilings force these aircraft to work in or above the instrument meteorological conditions, thereby reducing their ability to locate and attack low-flying helicopters.

Visibility will determine whether the flight can be conducted successfully. With current equipment, terrain flying cannot be performed when extremely poor visibility exists because of the aircrew's inability to detect obstructions and navigate accurately. Also, during poor visibility, visual cues for conducting external operations are reduced. As a result the pilot tends to induce load oscillation. During conditions of poor visibility, you may have to follow



FIGURE 5-15. WEATHER HAZARDS.

TERRAIN FLIGHT CAN BE CONDUCTED SUCCESSFULLY IN ADVERSE WEATHER SO LONG AS SUFFICIENT VISIBILITY EXISTS TO NAVIGATE ACCURATELY AND TO ALLOW OBSTACLE AVOIDANCE.

roads or rivers where masking cannot be achieved. If navigation must be performed, based on terrain orientation, greater visibility will be required to accomplish the mission. The success of an attack helicopter mission will be influenced by visibility in the objective area as well as enroute visibility. Engagement ranges will be closer. As a result the aircraft will be within the effective range of the weapon system being engaged. The success of a mission performed during adverse weather depends on how well the mission has been planned.

DETAILED PLANNING IS REQUIRED FOR MISSIONS PERFORMED DURING ADVERSE WEATHER CONDITIONS.

Since weather is often unpredictable, forecasts should be confirmed by troops in the area. When a multi-helicopter operation is necessary, it may be desirable to send a single aircraft into the area of operation to determine the weather conditions.

During flight in adverse weather conditions, it is essential that you maintain visual reference with the ground. Airspeed must be reduced based on the amount of visibility. Also, when flying along a road, altitude must be high enough to clear

wires. If disorientation occurs, stop and attempt to determine your exact location. If your position cannot be determined, return to the last known checkpoint and try again.

HELICOPTER IFR BREAKUP AND RECOVERY PLAN

When conducting flight during adverse weather conditions, the possibility exists that you may enter into instrument meteorological conditions (IMC). A pre-arranged breakup and recovery procedure should be established prior to conducting the flight. Each unit should have written into their SOP, helicopter IFR breakup and recovery procedures for single and multiple ship operations. A recommended procedure is outlined in chapter 9 of this publication. To insure mission accomplishment, a tactical instrument flight should be planned as an alternate course of action when conducting a mission during marginal meteorological conditions.

MAINTAINING VISUAL REFERENCE WITH THE GROUND IS ESSENTIAL WHEN TERRAIN FLYING IN ADVERSE WEATHER.

TRAINING PROGRAM

Terrain flight training should be conducted in two phases, initial qualification and advanced or unit training. Initial qualification training is designed to familiarize the aviator with aviation operations in the high threat environment and to teach navigation and flight skills needed to conduct terrain flight. Specific training objectives for initial qualification include—

☐ *Flight Training.*

○ Perform the tasks required to conduct NOE flight to include flight maneuvers and emergency procedures. Satisfying this training objective also involves teaching the aviator how to move; clearance judgment; aircraft size appreciation; and how to use the shadows, sun, and reduced visibility to his advantage. The skill of the aviator to conduct low-level and contour flight must also be evaluated and any required refresher training provided.

○ Perform the tasks required to conduct enroute terrain flight navigation in order to find the objective 100 percent of the time and to pinpoint the aircraft's location to within 100 meters or know the position in relation to a recognizable terrain or manmade feature located near the flight route.

○ Perform the tasks required to operate effectively in the cockpit. Aircrew communication is the most important aspect of this objective. This requires the development of communication techniques and standardized phraseology. These tasks also include development of teamwork; division of duties; and proper radio usage, discipline, and security.

☐ *Academic Training.*

○ Acquire a knowledge of the high threat environment. This instruction should include the capabilities and methods of employment of threat air defense weapons, electronic warfare equipment, artillery, and aircraft.

○ Acquire a knowledge of human factors in terrain flying such as fatigue and perception of the external environment, and their impact on mission accomplishment.

○ Acquire a knowledge of map and aerial photo interpretation and terrain flight navigational techniques.

○ Acquire a knowledge of the considerations for the selection of flight routes, determination of the proper terrain flight altitude; knowledge of the principles of "analysis of the area of operation"; and planning for the use of suppressive fires.

Upon completion of initial qualification training, the aviator is ready to participate in advanced training. Advanced or unit training is designed to train the individual to accomplish the unit mission in the high threat environment using terrain flight techniques.

It should be designed to convert the individual skill and knowledge of each aviator into unit proficiency. This involves developing teamwork, standing operating procedures, and coordination procedures. It also includes individual training in the mission operational requirements peculiar to a specific mission or aircraft. For example, the attack helicopter pilot must be proficient in NOE gunnery if he is to accomplish his mission. The scout must learn the visual observation techniques to be used while NOE. The utility pilot must learn to carry sling loads while conducting contour and low-level flight. These training requirements exist because the techniques required to accomplish these tasks differ at the low altitudes associated with terrain

flying. In most cases the mission operational requirements can be taught with minimum formal instruction. However, NOE gunnery, observation, and external load procedures and techniques require a specialized training program.

Unit training is mission-oriented and is tailored to the specific unit. Although there are many ways to accomplish unit training, the following guidelines will assist in developing the training program.

- ☐ In developing the unit training program, the commander should first identify the specific tasks required for the unit to accomplish its mission. The Army Training and Evaluation Program (ARTEP) for the unit will assist him in determining these tasks. He can then evaluate the effect of terrain flying on each task and determine his specific training requirements.

- ☐ The training should be developed beginning with the lowest echelon and continuing to the highest echelon of the unit which would normally operate as a whole. In the case of the air cavalry combat brigade, this could be the battalion. In the case of an air ambulance company, team training of two or three aircraft would be the highest echelon because the company will rarely accomplish its mission with more aircraft. The training should include development and practice of the coordination and operational procedures between adjacent units.

- ☐ The platoon leader should be a training manager. This is especially important in units where the platoons or the elements of the platoon could be expected to operate independently.

- ☐ The control procedures used during training should realistically reflect those which will be used in combat.

- ☐ Each flight should be conducted under a simulated tactical situation and executed in accordance with the situation. For example, if a flight route is from point to point and solely behind the division rear, 500 feet above ground level (AGL) might be a suitable altitude. When operating in the main battle area, NOE flight must be employed to avoid detection and engagements.

- ☐ As the unit learns how to move without being detected, there is virtually unlimited opportunity to introduce various combat situations. The training should continually progress in difficulty by the inclusion of various combat situations. Whenever possible, ground surveillance radar teams, to include air defense weapons, should be used to detect and report aircraft to simulate the Threat and evaluate training.

- ☐ To better educate the ground commander as to aviation operations in the high threat environment, aviation training should be conducted in conjunction with ground units.

- ☐ At least one-third of all unit training should be conducted at night.

- ☐ Training should periodically be conducted in areas that are unfamiliar to the crews in order to maintain navigational proficiency. This is critical because in combat a unit may not operate in the same area for extended periods.

☐ During team, section, and higher echelons of unit training, battle drill type training should be emphasized. The training must instill an instinctive and habitual reaction to specific and specialized tactical situations to eliminate confusion and to reduce the need for radio transmissions.

☐ Communication discipline and security must be emphasized throughout unit training.

☐ When the unit has become proficient in conducting terrain flight in clear weather, the training emphasis should be shifted to more adverse weather conditions in order to increase the unit's staying power. The skills that the aviator has learned relating to night flight, battle drill, and thorough planning are applicable to adverse weather training.

☐ The key factor for successful unit training is *realism*. In peacetime we live and train in a garrison environment. Tactical units are too often overburdened with administrative support requirements that conflict with their tactical training. Unit commanders are faced with many other "squeezes on training" such as personnel shortages and turbulence, budgetary constraints, and ever-increasing maintenance requirements. There must be a unilateral effort by everyone—from private to senior commander—to make our training simulate actual combat. We must practice as we intend to fight.

☐ The aviation safety officer will conduct a systematic hazard analysis of unit training areas and practice at least twice annually.

NOTE: If the aircraft used as the primary training vehicle during initial training is not the aircraft that will normally be flown, additional NOE training should be given in the mission aircraft. This training is necessary because of the differences in the way a particular maneuver looks and feels between aircraft and in certain cases, such as an autorotation, differences in how the maneuver is accomplished. For example, the quick stop feels different in a Cobra as compared to an OH-58, because the pilot sits so much higher in the Cobra. This training should be accomplished prior to conducting advanced training.

The need to maintain individual aviator proficiency in low-level, contour, and NOE flight is as critical a training requirement as is qualification. In those units which normally conduct terrain flying, maintaining individual proficiency will be achieved along with maintaining unit proficiency; however, there are many aviators who do not frequently conduct terrain flying. These aviators should undergo a refresher course before conducting terrain flight.

COMMAND RESPONSIBILITY

For effective accomplishment of initial and advanced training, commanders should plan and supervise training to insure—

☐ The aviator is qualified to operate aircraft at all altitudes associated with terrain flying and in all conditions necessary to accomplish the unit mission. Also, the training must prepare him to meet the range of inflight emergencies that can occur close to the surface.

- ☐ Training is standardized.
- ☐ Aviators are given adequate opportunities to maintain the knowledge and skill required to conduct terrain flying.
- ☐ The physical and psychological condition of the aviator does not distract from the individual training. If for any reason, an aviator's ability to conduct terrain flying is impaired or subject to doubt, the commander should prohibit that individual from participating in training or operations until the circumstances causing that condition have been corrected.
- ☐ Terrain flight training is conducted only in approved training areas.
- ☐ Adequate training areas are available and designated.
- ☐ Terrain flying, whether it be training or mission, is as closely supervised as conditions permit.
- ☐ Unit training programs are conducted under simulated conditions of the high threat environment. Because aviation units often conduct training in conjunction with training exercises of ground units, one of the primary requirements for the aviation unit commanders must be to insure that the ground commanders are aware of the training requirements of the unit and that the training is conducted in a simulated high threat environment. It is the aviation unit commander's responsibility to insure that his aircraft are employed in training as they would be in the high threat environment.

NOTE: The commander is the final authority on the capability of his unit to perform properly on the high threat battlefield. This authority and responsibility cannot be delegated. Rather it must be exercised by personal participation in training.

SELECTION AND TRAINING OF INSTRUCTOR PILOTS

If there is a single most important ingredient for aviation training success, it is the instructor pilot (IP). The IP is primarily concerned with teaching survival and mission accomplishment on the battlefield. This requires that he teach tactics, flight maneuvers, and emergency procedures. When selecting an IP, his skill as well as desire must be considered. Other considerations include his appreciation and understanding of the ground maneuver force, aviation tactical concepts, and the operational requirements and limitations in the high threat environment.

SKILL AND DESIRE ARE IMPORTANT CONSIDERATIONS WHEN SELECTING AN INSTRUCTOR PILOT.

Instructor pilots and standardization instructor pilots (SIP) will be appointed in accordance with AR 95-1. In addition to the requirements outlined in AR 95-1, before conducting terrain flight training, the IP and SIP must have completed a terrain flight training course; demonstrated to an SIP their ability to instruct in the various modes of flight; and be currently rated rotary-wing IP in the type and model aircraft in which flight maneuvers will be accomplished.

PRIOR TO TEACHING TERRAIN FLIGHT, THE INSTRUCTOR PILOT SHOULD BE THOROUGHLY FAMILIAR WITH THE TRAINING AREA.

Each instructor pilot must be given thorough instruction on the flight techniques, methods of instruction, and hazards of terrain flight training. In addition to learning what is to be taught and how to teach it, the IP must become familiar with the training area so that he can determine his location at all times without having to divert his attention to a map.

When the instructor pilot is teaching terrain flight, he has five primary training responsibilities, to include the following:

- ☐ Teach the aviator the techniques of aircraft handling at terrain flight levels.
- ☐ Teach navigation skills, to include map interpretation, terrain analysis, and preflight mission planning.
- ☐ Teach crew integration and teamwork techniques.
- ☐ Teach or supervise academic instruction during initial qualification training.
- ☐ Monitor standardization and proficiency during advanced training.

FLIGHT TRAINING TECHNIQUES OF INSTRUCTION

The instructor pilot should be given the incentive and responsibility to develop a training environment designed for the individual aviator. He must be allowed to determine the intensity of the in-cockpit

instruction. Through this instruction the vital skills, knowledge, and lessons learned are conveyed to the aviator. Comprehension of various aspects of training varies greatly with the individual, and the aviator should not proceed to the next higher plateau of training complexity until he has mastered the lower. The person best qualified to judge when the aviator is ready for his next step is the IP. By varying the problems and tasks assigned from within the cockpit on a day-to-day basis with the degree of difficulty increasing, the aviator's level of compensation and retention are controllably increased.

INSTRUCTOR PILOTS MUST DEMONSTRATE THEIR COMPETENCE AS AN INTEGRAL PART OF THEIR QUALIFICATION TO INSTRUCT.

Terrain flight instruction not only emphasizes the need for "hands on" training, but also for mental projection ahead of the aircraft. The aviator must be allowed to think for himself, make his own radio calls, and make his own decisions while flying the aircraft. The IP serves not only as an instructor, but also as a catalyst for provoking thought. This dual role requires an IP of the highest caliber. The success or failure of the training will rest primarily upon his shoulders.

The instruction should encompass a review of pertinent low-level and contour flight maneuvers as well as teaching flight maneuvers peculiar to the NOE environment. Included in these are approaches, takeoffs, masking/unmasking, quick stops, and in-ground-effect and out-of-ground-effect hovering, and emergency procedures. Instruction should also include

low-level autorotations. During this training, it is important that the IP emphasize precise execution of flight maneuvers. Clearance judgment should also be emphasized during flight training.

During academic training instruction, the aviator is taught the proper procedures for effective and accurate map interpretation and terrain analysis. It follows that during flight training instruction, the IP must insure that the proper methods and techniques of navigation are rigorously applied. The objective of navigation instruction is for the aviator to be able to locate the objective 100 percent of the time, and to pinpoint the aircraft's location to within 100 meters or know the position in relation to a recognizable terrain or manmade feature located along or near the course leg. If the aviator becomes disoriented or is having difficulty with a specific aspect of his navigational technique, the IP should assist by pointing out his weakness or error once he determines that the aviator will be unable to correct the faults himself. During "Phase II—Tactical Orientation," it is important that the IP encourage the aviator to use good judgment in his route selection and enroute navigation. For example, a route following a streambed selected during mission planning may look good because it appears to follow the lowest contour. However, hardwood trees commonly grow in streambeds and the tops may be considerably higher than the tops of the pines on the surrounding higher ground. In this case, the crew should deviate from the course to follow the lowest contour in the vegetation.

Instruction related to tactical employment must be realistic. Therefore, it should

be understood that there is no "school solution" to any tactical problem posed to the aviators. There are a number of possible courses of action, each with strong and weak points and with differing probable results when applied to varying situations. In the early phases of training, the IP should point these out and then allow the aviator to make the decision for himself. In the later stages, the aviator will arrive at his choice and implement it without any IP assistance or advice. If, however, the aviator makes a poor tactical decision or places his ship in simulated peril through inadvertent exposure to the enemy threat, the IP should conduct an immediate critique. He should explain to the aviator his mistake and the consequences of his error. This may be done at a slightly higher hover so that the terrain may be used to clarify the error. It may be necessary to reorient the aviator to allow execution of a better approach and continuation of the mission.

Formal grading of flight training progress is not necessary, but the IP should debrief the aviators after each flight on their manner of performance and progress or lack of progress. The evaluation flight should be graded as pass or fail. It is essential that the standards used adequately reflect the individual's competency. If he cannot find the objective 100 percent of the time, he cannot accomplish the mission no matter how well he satisfies the other performance objectives. Depending on local policies or individual instructor preference, IPs may use informal notes or printed gradeslips as an aid in conducting daily flight debriefings.

TRAINING SAFETY

Commanders may feel that individual and unit terrain flying programs will introduce unacceptable *training risks* and therefore jeopardize mission accomplishment. It is possible that some aircraft may be lost in training, but the magnitude of the threat dictates that training be conducted now, prior to an outbreak of hostilities. It can be done without neglecting the *controls and safeguards* needed to help prevent accidents.

☐ *Safety and Training Risks.* To help minimize the safety risks, commanders and leaders must strictly supervise and control the training to insure no independent experimentation is conducted. Unwavering adherence to flight standardization procedures is also essential to reduce training risks. The risks associated with terrain flying can be minimized with adequate supervision, control, and adherence to flight standardization procedures.

☐ *Control of Training.* Control is essential to insure safe training; but the commander must establish the proper balance between control, training realism, and supporting resources. The techniques suggested below provide a balance of control and tactical realism, but require a relatively high amount of supporting resources. These techniques are suggestions and should be modified as required based on the local situation, degree of aviation proficiency, and available resources.

During *initial qualification training* and the *individual night training* phases of advanced training, a commander should operate a centralized control system. To do

this, the following techniques should be used:

④ Safety and control aircraft should be used when several aircraft are training simultaneously to control training areas, insure traffic separation, create tactical situations, and provide rapid response in emergencies. The S&C aircraft should operate at an altitude so as not to interfere with the training aircraft. If the commander chooses not to employ an S&C aircraft, he should develop a "buddy system" to be used between training aircraft to help insure separation and provide rapid response.

④ Air control points, boundaries, and air (flight) corridors can be used effectively to control aircraft in training as well as during tactical missions.

④ Position reports should be used to maintain the location of each aircraft when numerous aircraft are training simultaneously. In addition to position reports being made at appropriate ACPs, they should be made any time the aircraft leaves the planned route.

④ A radio search should be conducted if a training aircraft has not reported to the S&C or his buddy aircraft within the preceding 15 minutes. To eliminate unnecessary air searches in the event a training aircraft experiences "lost commo," a lost communications rendezvous point should be identified in the training area. After experiencing lost communications, the training aircraft would proceed to the rendezvous point. Upon completing its radio search, the S&C aircraft would check the rendezvous point.

During the *unit training* phases of advanced training, the commander should decentralize control to realistically reflect operational control procedures that would be used during combat. He should rely heavily on his subordinate leaders to provide the necessary control and supervision of the S&C aircrew. He should closely monitor planning to insure that adequate control is planned by subordinate leaders and that training is realistic.

☐ *Safety and Control Helicopter Pilot Responsibility.* When the S&C aircraft is used, the pilot's duties should include those discussed below. The crew will assist the S&C pilot as he directs.

- The pilot will receive a briefing from the training officer on the contents of the S&C pilot's SOP and the specific duties of the S&C aircraft crew. He should be familiar with the training and safety SOPs.

- The pilot also monitors the preflight briefing of aviators and conducts preflight preparations. He must be familiar with the existing and forecasted weather to include the density altitude; ceiling; visibility; and wind velocity, direction, and gust spread. He must prepare a flight-following map and conduct a hazards map check. The flight-following map should depict all routes (corridors), air control points, landing zones, restricted areas, and hazards. Used in conjunction with the flight-following map is the flight-following log. This locally prepared form is used to log position reports from aircrews flight-following with the S&C aircraft.

- During training, the pilot maintains the flight-following log. He should have available the flight-following map, reporting requirements, operation orders for each route, and the training communications—electronics operating instructions (CEOI). He must remain in radio contact with each aircraft. If more than 15 minutes have elapsed since the last call from an aircraft, the S&C pilot will initiate a radio search. Also, he reports any unanticipated hazards—stray aircraft and inclement weather—to the training aircraft. Knowledge of the tactical mission and situation for each aircraft is a must since he issues and/or answers tactical calls while acting as the combined arms team's higher and adjacent headquarters.

- A critical responsibility of the S&C pilot is to control the entry of observer aircraft into the training area.

- The pilot remains on station until all training aircraft have departed or designates another (training) aircraft as an alternate S&C if he must leave station.

- If an air ambulance is not available, it is desirable that the S&C helicopter pilot have, in addition to his required crew, a medic and two personnel who are rappel-qualified with appropriate equipment.

☐ *Hazards Identification Map.* An important aid in helping to insure safety is the hazards map. A hazards map will be maintained that depicts hazards and restrictions within the unit's training areas. The map will be updated any time an unplotted hazard is located. Prior to conducting training, hazards will be marked on maps used by aircrews conducting terrain flight training.

☐ *Crossing Wires.* To conduct realistic terrain flight training, it may be necessary to fly under wires where adequate clearance exists. However, during training, flight under wires must be stringently controlled to prevent accidents. Therefore, wires should be underflown only at points where clearance has been predetermined to be sufficient. Wire obstacles built as training aids should utilize low tensile strength wire and have a breakaway capability. Thin wires can be made more visible by wrapping strips of masking tape on the wire.

TRAINING AREAS

Prior to conducting training, permission to use property not within the confines of military reservation for landing zones must be secured from property owners. This may be accomplished through coordination with the local installation engineer element which will obtain assistance through the district engineer headquarters. Because the noise associated with training at the low altitudes can be irritating, every effort should be made to familiarize people in affected areas with the need for the training. Good public relations is absolutely essential.

The following are considerations for the selection of training areas:

☐ The initial qualification training areas should be selected to develop the ability of the aviator/crewmember to navigate NOE as well as familiarizing him with the tactical applications of terrain flying.

☐ For advanced training, the training area must be selected to provide a realistic training environment based on unit mission.

☐ Army Regulations and Federal Aviation Regulations pertaining to controlled airspace can induce additional restrictions or restrict training areas.

☐ A critical task associated with terrain flying is the continuing elevation of the aircraft location and its relationship to enemy air defense weapons and intermittent terrain. Therefore, the training area should offer a wide range of terrain relief in order to train the aviator to evaluate his altitude options during planning and flight.

☐ The training area should have as few hazards and obstacles as possible.

☐ The training area should be selected to avoid population concentrations.

☐ The training area should also provide suitable space to conduct instruction in NOE flight maneuvers.

☐ Training areas should include primary and alternate landing zones to be used for preplanned or on-order missions. Landing zones should be free of crops and covered with sod.

CHAPTER 6

NIGHT FLIGHT

SECTION I. NIGHT VISION

NIGHT VISION LIMITATIONS

Of all the sensory means you use in flight, your eyes are the most important. You need good depth perception for safe landings and takeoffs and good visual acuity for identifying terrain features and obstacles which lie along the flightpath. When flight is conducted during daylight hours, the eyes can easily perceive visual cues; however, during hours of darkness, illumination is reduced and the unaided eye is limited as to what can be seen. Flight

personnel who have 20/20 day vision may not possess an adequate night vision capability. This may be caused by a physical deficiency or a self-imposed limitation—smoking, for instance. It is important that you be aware of your deficiencies and limitations before conducting night flight. Avoidance of self-imposed limitations will assist you in achieving good night vision.

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Laboratory tests have proven that having good night vision does not automatically guarantee the most effective use of this capability. Unless you are trained, you will find it difficult to identify an object at night. Although the limits of night vision vary from person to person, experience shows that most aviators have never learned to use their night vision to its fullest capacity. An aviator with an average night vision capability who knows techniques of night vision is far better off than an aviator with superior night vision who doesn't know "how to see."

There are two visual deficiencies which may become more apparent at night. They are:

□ *Presbyopia.* A common deficiency which occurs after age 40 is presbyopia, which is a loss of the eye's ability to accommodate to diverging light rays from near objects. A hardening of the lens occurs

which adversely affects the eye's ability to focus red light on the retina. Instruments which are illuminated with red light become blurred and difficult to read. This difficulty can be corrected with certain types of bifocal spectacles which compensate for the inadequate accommodative power of the lenses of the eyes.

□ *Night Myopia.* At night, the spectrum of available light changes so that the blue wavelengths of light prevail. Because of this condition, an individual who is slightly near-sighted (myopic) will experience more difficulty at night. This could result in blurred vision if not corrected by special night mission spectacle lenses. Individuals having this difficulty should seek the advice of a flight surgeon. Special corrective lenses can be prescribed to correct for myopia.

Because of the technical medical nature of this section, it is annotated with

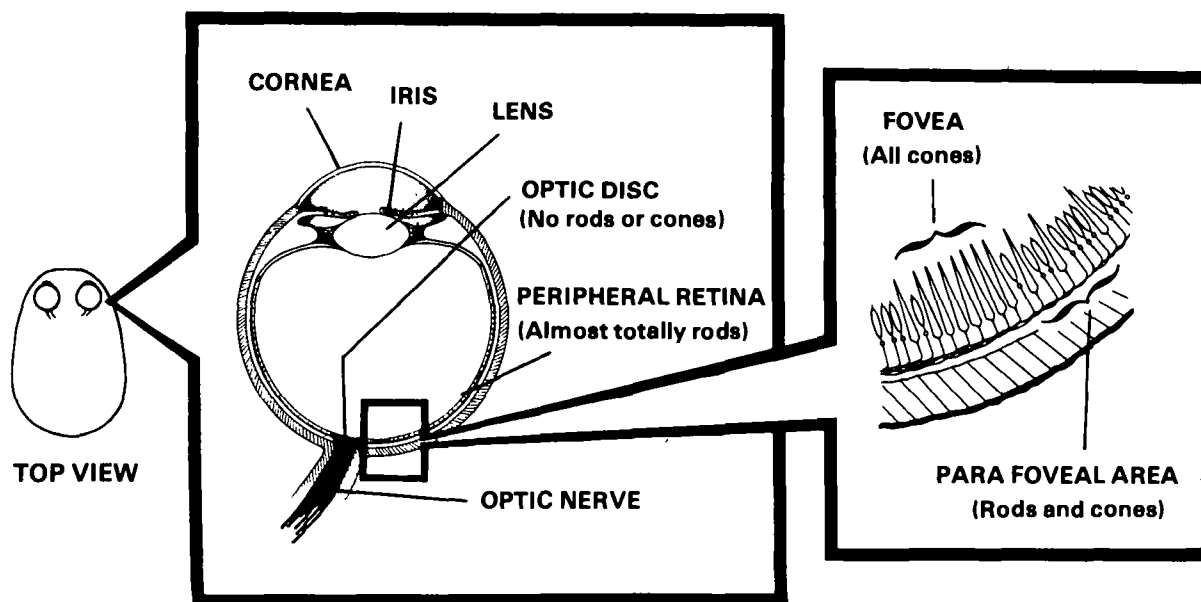


FIGURE 6-1. ANATOMY OF THE EYE.

superscript numerals. Commentary notes corresponding to these are found in appendix B. The notes are not essential to a practical understanding of the test, but are provided for personnel requiring an in-depth explanation of specific technical terminology.

ANATOMY AND PHYSIOLOGY OF THE EYE

The eye functions similarly to a camera and consists of two main parts (fig 6-1).

□ The cornea, lens, and iris combination gathers and controls the amount of light that is allowed to enter the retina.

□ The retina can be compared to a photographic film. It is a sensitive layer upon which the light is focused to form an image.

The visual center of the retina is called the fovea centralis. It contains only cones which operate most efficiently at ordinary illumination such as those that prevail throughout the day and in normally lighted rooms at night. Cones provide for the perception of color. As light levels are reduced, normal color vision becomes less sensitive and finally disappears. Runway light colors can be identified because the light is of sufficient intensity for the cones to perceive color. If the color of an object or terrain feature is to be recognizable at night, it must be illuminated with sufficient light intensity to permit cone perception of colors. During darkness or in dim illumination, central vision becomes less effective and a relative blind spot (5° to 10° wide)¹ develops (fig 6-2). This results from the relatively light insensitive elements concentrated in the area immediately surrounding the retina of the fovea centralis. Since the central fields of vision

¹ See notes in appendix B.

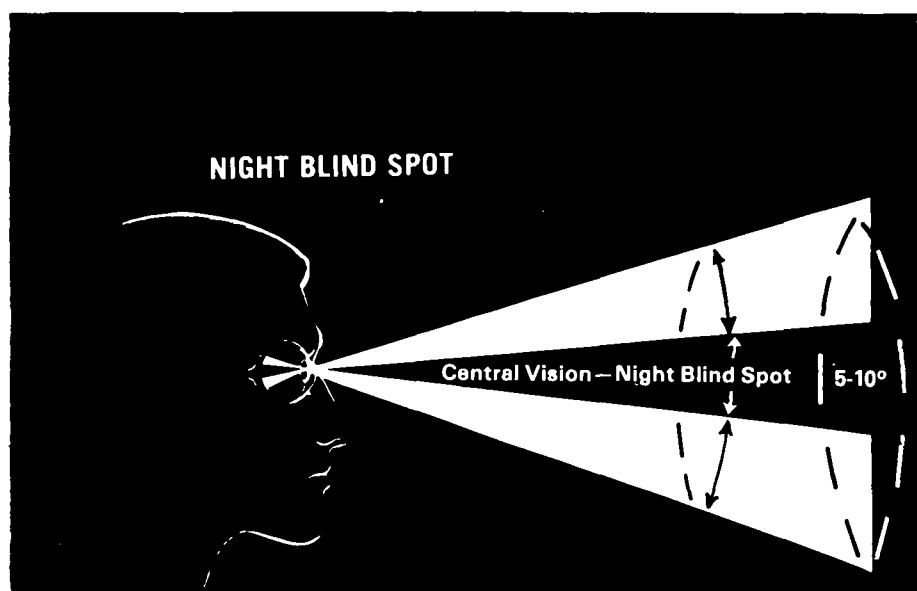


FIGURE 6-2. NIGHT BLIND SPOT.

for each eye are superimposed for binocular vision, a single night blind spot appears.^{2,3} If an object is viewed directly, it may not be detected due to the blind spot; if detected, it will fade away more rapidly. As a result of the projected central blind spot,⁴ larger and larger objects will not be seen as the viewing distance increases (fig 6-3).

The remainder of the retina contains rods and cones with rods increasing in relative number toward the periphery of the eye. As previously stated, the central retina is capable of highly acute vision in high illumination due to the concentration of cones. The peripheral retina consists of almost all rods. Rods perceive only shades of gray. Because of the way they are connected to the brain, they only perceive form or shape; therefore, peripheral vision is less precise than central vision. However, rods are about 1,000 times as

sensitive to light as cones. They are the primary visual receptor in dim illumination and thus provide night vision. Greatest sensitivity of the rods is achieved after 30 to 45 minutes in a dark environment. Exposure to light sources tends to bleach out the rods and reduces the night vision capability of the rods. Because visual acuity is reduced at night, objects must be identified by their shape or silhouette.

TYPES OF VISION

There are three types of vision. Each type requires different sensory perceptors for interpretation of an image. The three types of vision are:

□ *Photopic Vision.* Photopic vision is experienced during daylight hours or when a high level of artificial illumination⁵ exists. Under these conditions, perception is achieved primarily by the cones, especially those concentrated in the fovea

^{2,3,4,5} See notes in appendix B.

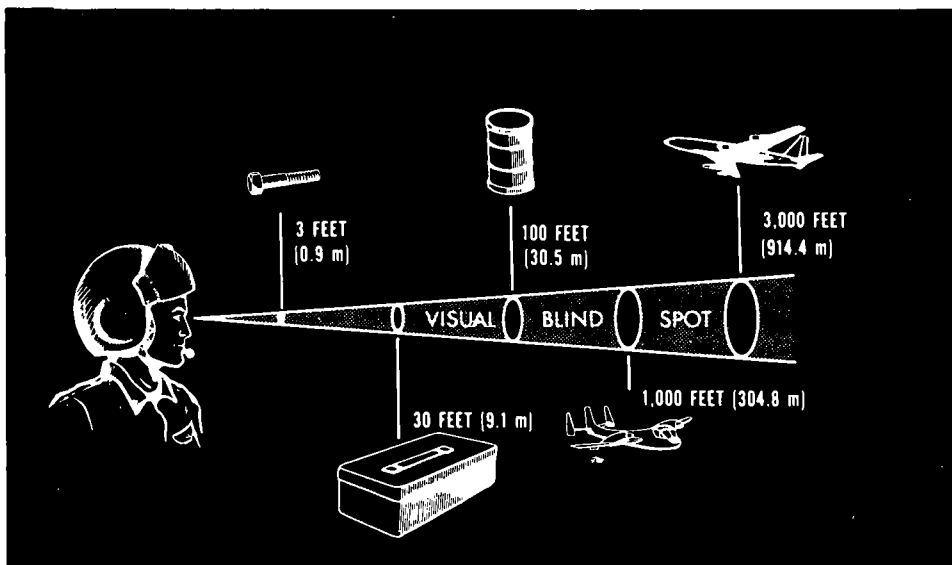


FIGURE 6-3. EFFECTS OF NIGHT BLIND SPOTS.

centralis. Due to the high light condition, rod cells are bleached out and become less effective. Sharp image interpretation and color vision are characteristic of photopic vision. The fovea centralis of the eye is automatically directed toward an object by a visual fixation reflex. Therefore, under photopic conditions, the eye views objects along the central visual axis of the eye and scans a field of view using primarily central vision.

□ *Mesopic Vision.* Mesopic vision is experienced at dawn, dusk, and during periods of high light levels. Vision is achieved by a combination of rods and cones. Visual acuity steadily decreases as the available light declines. A reduction in color vision occurs as the light level decreases and the cones become less effective. Due to gradual loss of the cone sensitivity, greater emphasis should be placed upon offcenter vision for detection of objects.

□ *Scotopic Vision.* Scotopic vision is experienced when low-level light conditions exist. Cone cells become ineffective, causing poor resolution of detail. Visual acuity decreases to 20/200 or less⁶ and total loss of the color perception occurs. A central blind spot occurs due to the loss of cone sensitivity. Peripheral vision is the only means of seeing. Viewing of objects must be accomplished by off-center viewing. The natural reflex of looking directly at an object must be reoriented by night vision training. The use of scotopic vision demands searching movements of the eyes to locate an object and small eye movements to keep the object in sight. A characteristic of scotopic vision is that an image will fade away completely if the eyes are held stationary on an object for more than a few seconds.

⁶ See notes in appendix B.

DARK-ADAPTATION

Dark-adaptation is the process by which the eyes increase their sensitivity to low levels of illumination. Rhodopsin (visual purple) is the substance in the rods responsible for light sensitivity. The degree of dark-adaptation increases as the amount of visual purple in the rods increases through biochemical reactions. Each person will dark-adapt to varying degrees and at different rates. In a darkened theater, the eye adapts rather quickly to the prevailing level of illumination. Compared to the light level of a moonless night, this is rather high. However, less time would be required to dark-adapt in complete darkness after being exposed to the light level of the theater as compared to the brightness of a lighted hangar. Thus, the lower the starting level of illumination, the more rapidly complete dark-adaptation is achieved. Dark-adaptation for optimum night visual acuity approaches its maximum level in approximately 30 to 45 minutes under minimal lighting conditions. If the dark-adapted eye is exposed to a bright light after dark-adaptation, the sensitivity of that eye is temporarily impaired. The degree of impairment depends on the intensity and duration of the exposure. Brief flashes from a white (xenon) strobe light of high intensity will have a minimum effect upon night vision because the pulses of energy are of such short duration (milliseconds). Exposure to a flare or a searchlight beam which would normally be for a period in excess of 1 second could seriously impair your night vision. Depending upon the brightness and duration of such an exposure, the recovery of a previous maximum level of dark-adaptation could take from 5 minutes to the full 45 minutes in continued darkness.

Exposure to bright sunlight has a cumulative and adverse effect on dark-adaptation. This condition is intensified by reflective surfaces such as sand and snow. Exposure to intense sunlight for 2 to 5 hours will cause a definite decrease in photopic visual sensitivity which can persist for as long as 5 hours. In addition, the rate of dark-adaptation and the degree of night visual capacity will be decreased. These effects are cumulative and may persist for several days.

The retinal rods are least affected by the wavelength of a dim red light source. Because the rods are stimulated so slightly, night vision is not significantly impaired when viewing red lights if the proper techniques are used. To minimize the adverse effect of red lights on night vision, adjust the light intensity to the lowest usable level and view the light for only short periods of time.

PROTECTION OF NIGHT VISION

To minimize the time required to attain dark-adaptation and to protect against the loss of night vision you should:

☐ Wear military neutral density (N-15) sunglasses or equivalent filter lenses when exposed to bright sunlight. This precaution will maximize the rate of dark-adaptation at night and improve your night visual sensitivity.

☐ Use only red lights in the cockpit. The intensity of the cockpit lights should be adjusted to the lowest level which will allow you to interpret the instruments or the map. The duration and frequency of preexposure to the cockpit lights should be minimized.

☐ Turn off or tape exterior lights.

☐ Wear approved red-lens goggles prior to the execution of a night operation. This procedure allows you to begin dark-adaptation in an artificially illuminated room and decreases the possibility of undesirable effects from accidental exposure to bright lights, especially when going from the briefing room to the flight line. The wearing of red-lens goggles does not allow you to completely dark-adapt if exposed to a light source. However, the time required to dark-adapt is reduced by wearing the goggles.

☐ Prepare takeoff and landing facilities for night flight. Refer to facility requirements, section IV for this information.

When performing a night tactical air mission, you can anticipate battlefield and meteorological conditions—artillery flashes, flares, searchlights, lightning—which will cause total or partial loss of your night vision. When confronted with these conditions, the following techniques should be used:

☐ If a flash of high intensity light is expected from a specific direction, turn the helicopter away from the light source. When a condition such as lightning occurs unexpectedly and direct view of the light source cannot be avoided, dark-adaptation can be preserved by covering or closing one eye while using the other eye to observe. When the light source is no longer a factor, the eye which was covered will provide the night vision capability required to conduct flight because dark-adaptation occurs independently in each eye.

CAUTION: Difficulty will be experienced with depth perception when viewing with the dark-adapted eye, particularly when hovering near terrain obstacles and during approach.

☐ Flight routes should be selected to avoid built-up areas where a heavy concentration of lights would be encountered. If these conditions are inadvertently encountered, the flight route should be altered to avoid overflight of the brightly illuminated area. Loss of dark-adaptation from a single light source such as a farmhouse or an automobile can be avoided by turning the head and eyes away from the light.

☐ When flares are being used to illuminate the viewing area or if they are inadvertently detonated near your position, maneuver the helicopter away from the flare to a position along the periphery of the illuminated area. When maneuvering the helicopter, turn in a direction so that your position is on the side away from the light source. This procedure minimizes your exposure to the light source.

☐ To minimize the effect of weapon flashes from aerial weapon systems, you must limit the duration of time during which the ordnance is expended. Rockets can be fired in almost any combination without serious impairment of night vision. When firing automatic weapons, use short bursts of fire.

☐ Night vision is dependent upon optimum function and sensitivity of the rods of the retina. Lack of oxygen to the rods (hypoxia) significantly reduces their sensitivity and causes an increase in the time required for dark-adaptation and a decrease in the ability to see at night.

Without supplemental oxygen, a measurable decline in night vision is evident at pressure altitudes in excess of 4,000 feet. For this reason, when flying at night, it is recommended that oxygen be used at pressure altitudes above 4,000 feet.

SELF-IMPOSED STRESSES

There are limitations to night vision which are self-imposed. An awareness of these self-imposed restrictions is essential to insure that each is avoided before participating in night flight.

☐ *Smoking and Night Vision.* Cigarette smoking significantly increases the amount of carbon monoxide carried by the hemoglobin of red blood cells, thus reducing the blood's capacity to combine with oxygen. Hypoxia caused by carbon monoxide poisoning affects night visual sensitivity and dark-adaptation in the identical way and to the same extent as hypoxia resulting from high altitude. Smoking three cigarettes in rapid succession, or 20 to 30 cigarettes within a 24-hour period prior to a flight, may saturate from 8 to 10 percent of the capacity of the hemoglobin of the red blood cells in the body. The physiological effect of this condition is that the smoker has effectively lost 20 percent of his night vision capability at sea level.

☐ *Alcohol and Night Vision.* Alcohol has the effect of sedating a person, thus causing lack of coordination and impairment of judgment. As a result, you fail to apply the proper techniques of night vision. You begin to stare at objects and your scanning techniques become disorganized. Alcohol, like cigarette smoking, impairs night vision, but to a greater extent. The two in combination are cumulative. The degree to which night vision is affected is

determined by the amount of alcohol consumed. Hangover aftereffects also impair visual scanning efficiency.

☐ *Fatigue and Night Vision.* If you are fatigued when performing night flight, you will not be mentally alert. As a result, you will not apply the proper techniques of night vision. Your response to situations which require immediate reaction will be slow. You tend to concentrate your attention in one area without consideration for the total requirement. Depending on the degree of fatigue, your performance may become a safety hazard.

☐ *Sickness and Night Vision.* Normally associated with sickness is an increased temperature and feeling of unpleasantness. High body temperatures consume a higher rate of oxygen than is normally required. As a result, relative hypoxia is induced and degradation in night vision may occur. In addition, the unpleasant feeling that is associated with sickness will distract your attention and restrict your ability to concentrate on night flying requirements.

☐ *Nutrition and Night Vision.* Failure to eat foods that provide sufficient vitamin A could cause impairment of night vision. Foods that are high in vitamin A content are eggs, butter, cheese, liver, apricots, peaches, carrots, squash, spinach, peas, and all types of greens. An adequate intake of vitamin A is normally provided by a balanced diet. Excess quantities of vitamin A will not increase your night vision ability and may be harmful. Stomach contractions (hunger sensations) which result from missed or postponed meals will exert an unpleasant feeling and cause distraction, breakdown in habit pattern, shortened

attention span, and other physiological trait changes.

☐ *Physical Conditioning and Night Vision.* Because of the physiological stresses of night flight, you will become more easily fatigued. To overcome this limitation, you should participate daily in organized athletic programs. Good physical fitness will help you conduct night flight with less fatigue and improve your night scanning efficiency.

NIGHT VISION TECHNIQUES

Dark-adaptation is only the first step toward maximizing your ability to see at night. In order to see effectively in the dark, you must apply night vision techniques which will enable you to overcome physiological limitations of your eyes. During daylight hours, objects can be perceived at a great distance with good detail. At night the range is limited and detail is poor. A sound basic principle of visual scanning, day or night, is to view the area of concern by moving the head and eyes together as a unit. Movement of the eyes, independent of the head—sideways or vertically—will, in some cases, reduce the overlap provided by binocular vision.

The technique used when scanning the terrain along the flightpath is an important consideration if objects are to be identified at night. To scan effectively, scan from right to left or left to right (fig 6-4). Begin scanning at the greatest distance an object can be perceived (top) and move inward toward your position (bottom). Due to the inability of the light-sensitive elements of the retina to perceive images while in motion, use a stop-turn-stop-turn type

motion. Each time you stop, scan an area approximately 30° in width. This viewing angle will subtend an area approximately 250 meters wide at a distance of 500 meters. The duration of each stop is based on the degree of detail that is required, but should be no longer than 2 to 3 seconds. When moving from one viewing point to the next, overlap the previous field of view by 10° . This technique allows you to view the periphery of the area being observed with greater clarity.

Viewing an object using central vision during daylight poses no limitation; however, if this same technique is used at night, the object may not be seen. This is due to the night blind spot that exists during periods of low illumination. To compensate for this limitation, "offcenter vision" must be used. This technique requires that an object be viewed by

looking 10° above, below, or to either side rather than directly at the object. This allows the peripheral vision of the eyes to maintain visual contact with an object.⁷ Figure 6-5 depicts the correct viewing technique.

Even though offcenter vision is practiced, if an object is viewed for a period of time in excess of 2 to 3 seconds, the images tend to bleach out and become one solid tone. As a result, the object can no longer be seen, thus inducing a potentially unsafe operating condition. To overcome this limitation of night vision, you must be aware of the phenomena and avoid viewing an object longer than 2 or 3 seconds. By shifting the eyes from one offcenter point to another, the object will continue to be acquired in the peripheral field of vision.

⁷ See notes in appendix B.

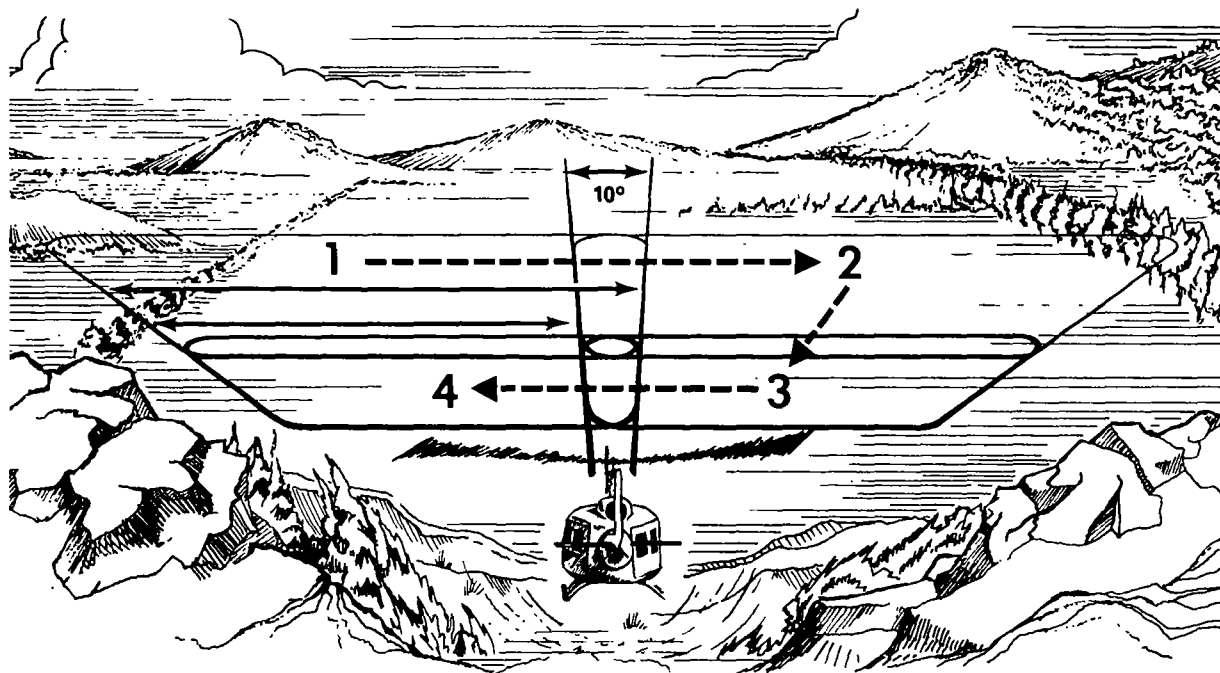


FIGURE 6-4. SCANNING PATTERN

Visual acuity will be significantly reduced at night. Because of this limitation, objects must be identified by their shape or silhouettes. Your ability to recognize objects using this technique will be determined by your familiarity with the architectural design of the structures which are common to the area in which the mission is being flown. A silhouette of a building with a high roof and a steeple can be easily recognized as a church in America; however, churches in other parts of the world may have a low-pitched roof with no distinguishing features. Manmade features depicted on the map will also assist in recognition of silhouettes observed while in flight.

DISTANCE ESTIMATION AND DEPTH PERCEPTION

The cues to distance estimation and depth perception are easily recognizable using central vision during good illumination. As the light level decreases, your ability to accurately judge distances is degraded and your eyes are more subject to seeing illusions. A knowledge of the mechanisms and cues to distance estimation and depth perception will assist you in making a better judgment of distance at night.

There are various mechanisms and cues used to judge distance. An estimation of

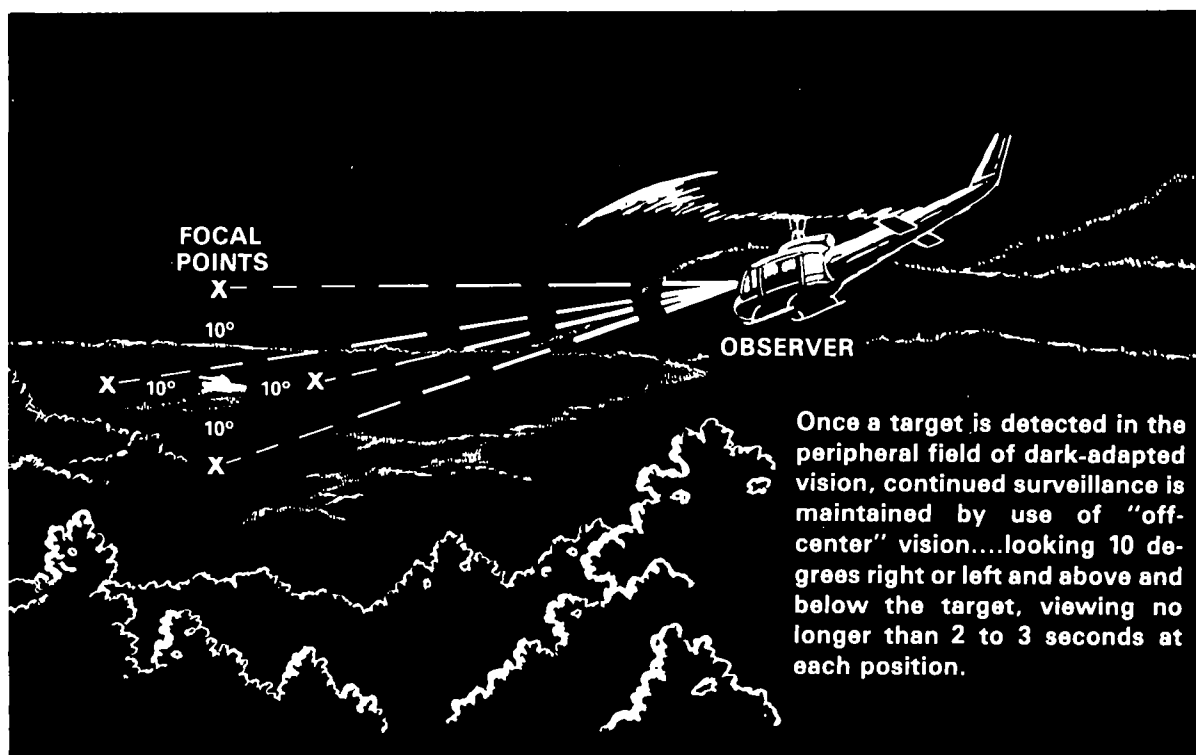


FIGURE 6-5. OFFCENTER VISION.

distance in a situation can be derived by using one mechanism or by using a combination of several mechanisms and cues. These estimations are usually derived on a subconscious level; that is, without the individual being aware of the evidence used to base the decision as to distance. By understanding these mechanisms or cues to estimation of distance, you may look for—or be aware of—additional cues beyond those which you would habitually use, and thus make a more accurate estimation of distance. These cues to distance or depth perception are monocular—only one eye is required for judgment—or binocular. The binocular cues depend on the slightly different view

each eye has of the object. Consequently, binocular perception is of value only when the object is close enough to make a perceptible difference in the viewing angle of the two eyes.

In flying, most of the distances outside the cockpit are so great that the binocular cues are of little, if any, value. In addition, these cues operate on a more subconscious level than the monocular cues; therefore, they are not as capable of being improved by study and training and will not be discussed here. Monocular cues used to aid in distance estimation and depth perception are:

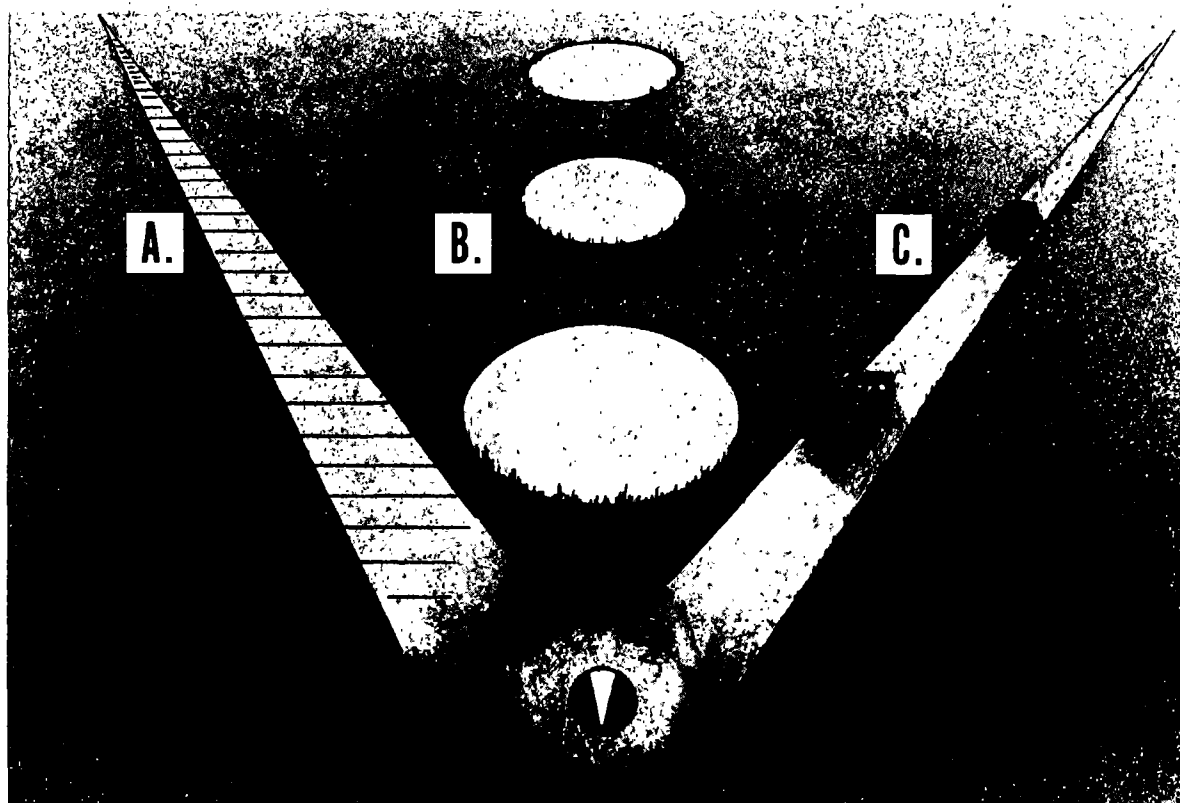


FIGURE 6-6. GEOMETRIC PERSPECTIVE.

□ *Geometric Perspective.* An object has an apparent different shape depending on the distance and angle from which it is being viewed. Types of geometric perspective are:

○ *Linear perspective.* Parallel lines such as railroad tracks (A, fig 6-6) tend to converge as distance increases from the observer.

○ *Apparent foreshortening.* The true shape of an object or terrain feature appears elliptical when viewed from a distance. As the distance to the object or terrain feature decreases, the apparent perspective changes to its true shape or form. B, figure 6-6 illustrates how the shape of a body of water changes when viewed at different distances.

○ *Vertical position in the field.* Objects or terrain features which are farther away from the observer appear higher on the horizon than objects or terrain features that are closer to the observer. The highest vehicle in C, figure 6-6 appears to be closest to the top and is judged as being the greatest distance from the observer.

□ *Motion Parallax.* This cue to depth perception is often considered the most important. Motion parallax refers to the apparent relative motion of stationary objects as viewed by an observer moving across the landscape. Near objects appear to move backward, past, or opposite the path of motion; far objects seem to move in the direction of motion or remain fixed. The rate of apparent movement depends on the distance you are from the object. Objects near the aircraft move rapidly, while

distant objects appear to be almost stationary. Thus, objects that appear to be moving rapidly are judged to be near while those moving slowly are judged to be at a greater distance. For example, if you are driving along a road, a picket fence near the roadside whizzes by. A tree not far from the roadside passes more slowly. Mountains in the distance appear to be fixed or moving with the vehicle and its occupant. From this observation, it is judged that the mountain is the greatest distance from the observer.

□ *Retinal Image Size.* The size of an image focused on the retina is perceived by the brain to be of a given size. Factors that are used to determine distance using the retinal image are:

○ *Known size of objects.* The nearer an object is to the observer, the larger is its retinal image. By experience, the brain learns to associate the distance of familiar objects by the size of their retinal image. A structure will subtend a specific angle on the retina, based on the distance from the observer. If the angle is small, the observer judges the structure to be at a great distance. A large angle would be judged by the observer as the building being close (fig 6-7). To use this cue, you must know the actual size of the object and have prior visual experience with it. If no experience exists, an object's distance would be determined primarily by motion parallax.

○ *Increasing/decreasing size of objects.* If the retinal image size of an object increases, it is approaching or moving nearer; if it decreases, it is retreating or moving farther away; if constant, it is at a fixed distance.

● *Terrestrial associations.* Comparison of an object such as an airfield with an object of known size, such as a helicopter, will help to determine its relative size and apparent distance from the observer. Objects ordinarily associated together are judged to be at approximately the same distance. For example, a helicopter that is observed in the near vicinity of an airport is judged to be in the traffic pattern and therefore at approximately the same distance to the field (fig 6-8).

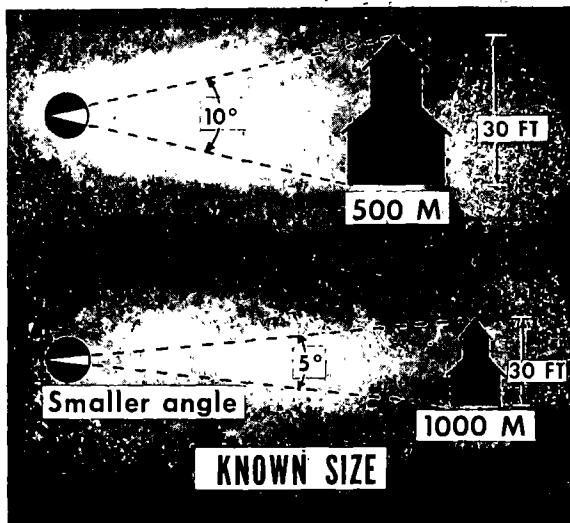


FIGURE 6-7. KNOWN SIZE.

● *Overlapping of contours or interposition of objects.* When one object is seen to overlap another, the object which is being overlapped is farther away. Otherwise stated, an object partly concealed by another object is behind (fig 6-9).

□ *Aerial Perspective.* The clarity of an object and shadow cast by the object is perceived by the brain and is used as a cue for estimating distance. Factors used to determine distance using aerial perspective are:

● *Fading of colors or shades with distance.* Objects viewed through haze, fog, or smoke are seen less distinctly and appear to be at a greater distance than they actually are. If atmospheric transmission of light is nonrestricted, an object is seen more distinctly and appears to be closer than it actually is. For example, the cargo helicopter (fig 6-10) is larger than the observation helicopter but, because of the difference in viewing distance and size, they both subtend the same angle on the observer's retina. Therefore, from this cue alone, assuming no previous experience with the appearances, both helicopters

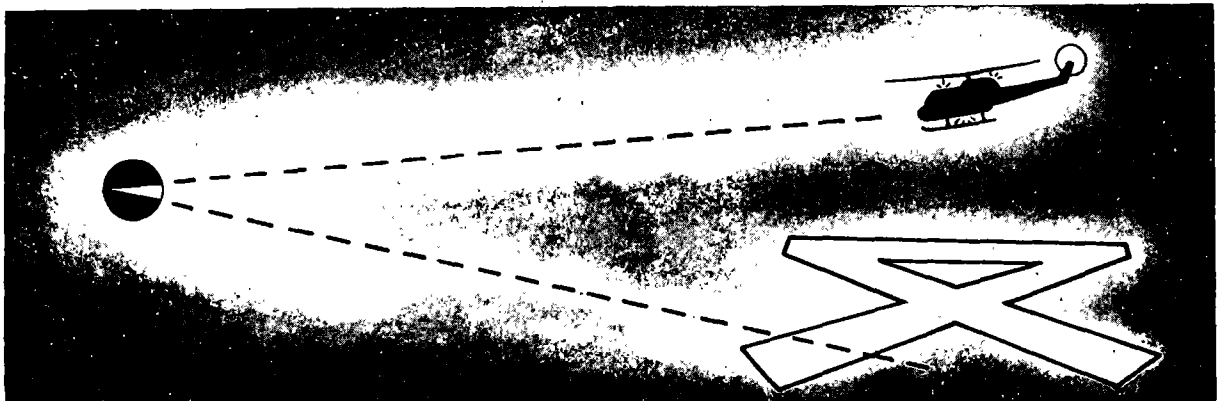


FIGURE 6-8. TERRESTRIAL ASSOCIATION.

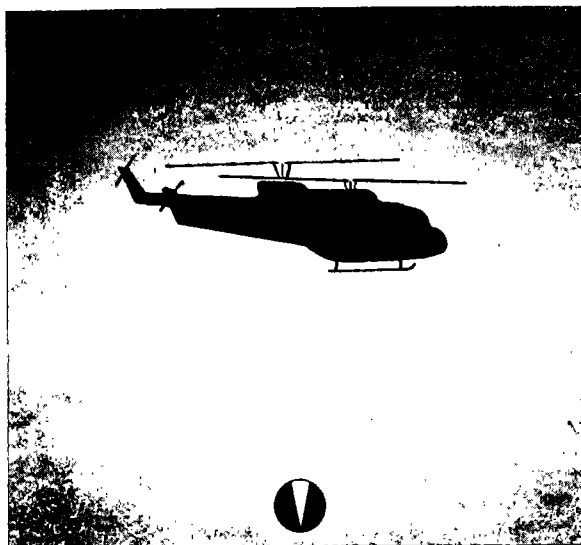
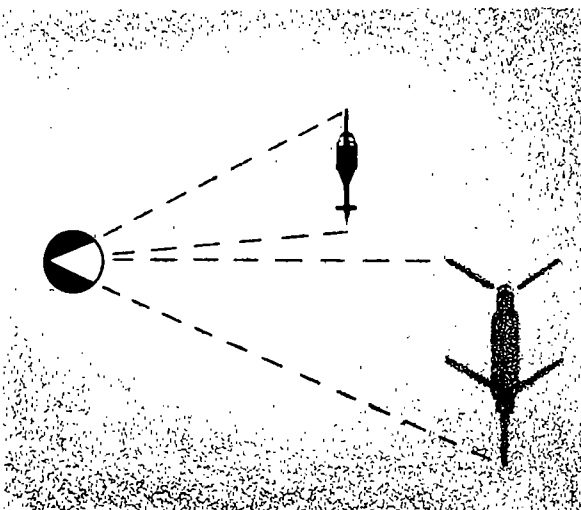


FIGURE 6-9. OVERLAPPING CONTOUR.



FIGURE 6-11. LIGHT AND SHADOWS.

FIGURE 6-10. FADING COLOR OR SHADE
WITH DISTANCE—

appear the same size. However, if the cargo helicopter is seen less distinctly because of visibility restrictions, it would be judged to be a greater distance away and larger than the observation helicopter.

● *Loss of discrimination or texture.* As you get further from an object, discrete

details become less apparent; e.g., a cornfield becomes a solid color, the leaves and branches of a tree become a solid mass, and the object is judged to be at a great distance.

● *Light and shadows.* Every object will cast a shadow if there is a source of light. The direction the shadow is cast depends on the position of the light source. If a shadow of an object is toward the observer, the object is closer to the observer than the light source (fig 6-11).

VISUAL ILLUSIONS

With decreasing visual information, there is an increased probability of spatial disorientation. Reduced visual references also create several illusions that can induce spatial disorientation. Visual illusions which occur in the aviation environment are:

□ *Autokinesis.* Autokinesis, or the autokinetic illusion (fig 6-12), is the illusory

phenomenon of movement which a static light exhibits when stared at in the dark. This phenomenon can be readily demonstrated by staring at a lighted cigarette in a dark room. Apparent movement will begin after approximately 8 to 10 seconds. Although the cause is not known, it appears to be related to the loss of surrounding references which normally serve to stabilize your visual perceptions. This illusion can be eliminated or reduced by visual scanning, by increasing the number of lights, or by varying the light intensity. The most important of the three

is the visual scanning technique. You should not stare at a light or lights for periods longer than 10 seconds. This illusion is not exclusively limited to lights in darkness. It can occur whenever a small, bright, still object is stared at against a dull dark, or nondescript background. Similarly, it can occur when viewing a small, dark, still object against a light, structureless environment. Any time visual references are not available, you are subject to experience this illusion. An awareness of this condition and how to cope with it is essential to insure safe operations at night.

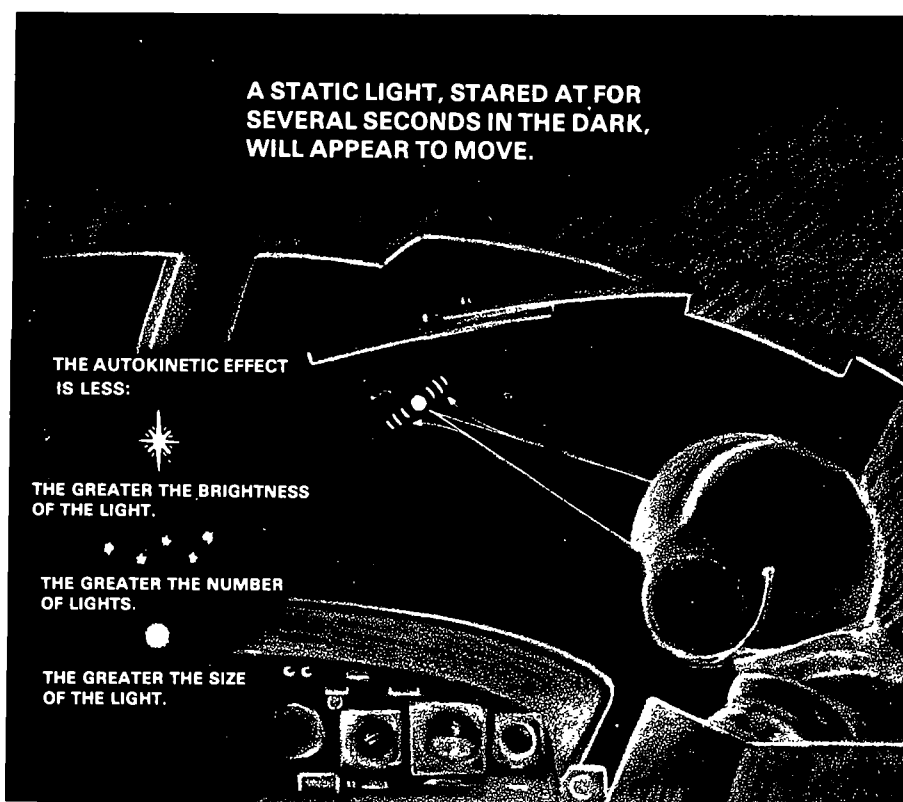


FIGURE 6-12. AUTOKINETIC ILLUSION.

□ *Confusion of Ground Lights With Stars.* A common occurrence is to mistake ground lights for stars. When this happens the aviator unknowingly positions the helicopter in an unusual attitude in order to keep the ground lights above him. Some aviators, for example, have misinterpreted the lights along a seashore as being the horizon and maneuvered their helicopter dangerously close to the sea while under the impression of flying straight and level (A, fig 6-13). Aviators have also confused certain geometric patterns of ground light—such as streetlights—with a runway or identified ground lights as an aircraft (B, fig 6-13).

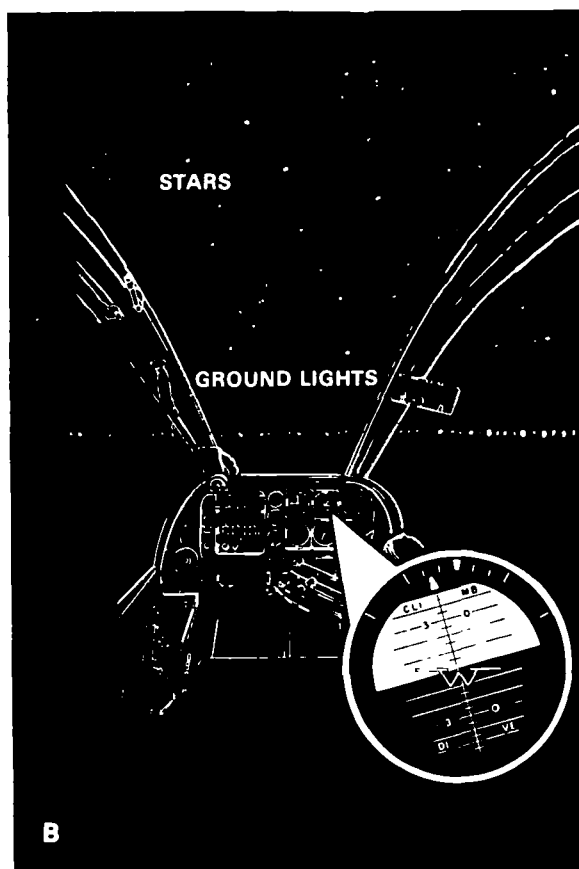
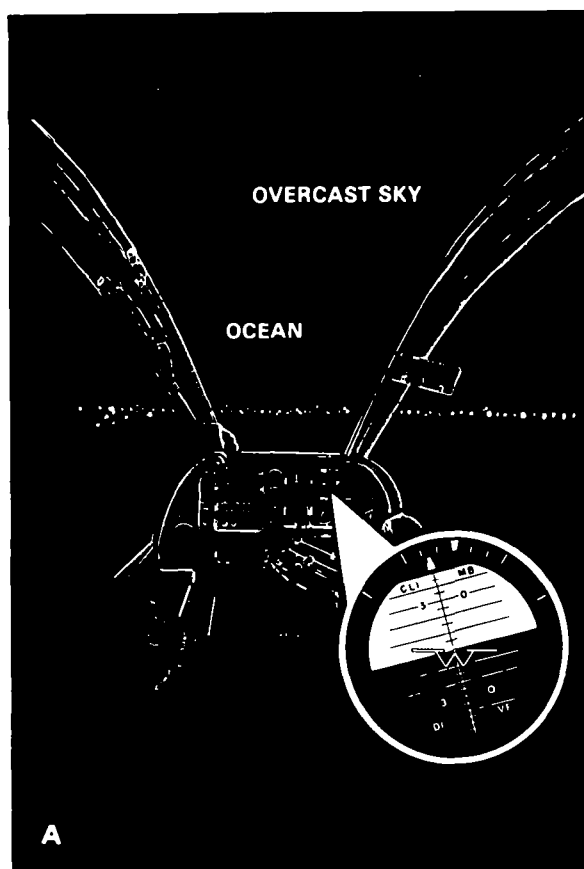


FIGURE 6-13. GROUND AND SKY LIGHT ILLUSION.

☐ *Relative Motion.* The illusion of relative motion is similar to a person sitting in a car at a railroad crossing waiting for a train to pass. Even though the car is not moving, the person in the car has the sensation that it is moving. You may encounter this illusion during formation flying. Motion by the wingman or leader may be interpreted as movement of your aircraft. The only way you can correct for this illusion is to have sufficient experience to understand that such illusions do occur and not to react to them on the controls.

☐ *Reversible Perspective Illusion.* An aircraft may appear to be going away when it is in fact approaching your position. This illusion is often experienced when an aircraft is flying parallel to your course. To determine the direction of flight, observe aircraft lights. If the intensity of the lights increases, the aircraft is approaching your position. If the lights become dimmed, the aircraft is going away.

☐ *False Horizons.* The illusion of false horizons is experienced when an object other than the actual horizon is interpreted to be horizontal to the horizon. For example, a helicopter flying between two cloud banks may be flown in relationship to the lower cloud bank because you feel that the lower cloud bank is horizontal to the horizon. In actuality the lower cloud may be at an angle to the horizon. You will attempt to level the helicopter in reference to the cloud which will put the helicopter in a turn (fig 6-14).

☐ *Altered Planes of Reference.* When approaching a line of mountains or clouds, you see the illusion of a need to climb even though altitude to clear is adequate.

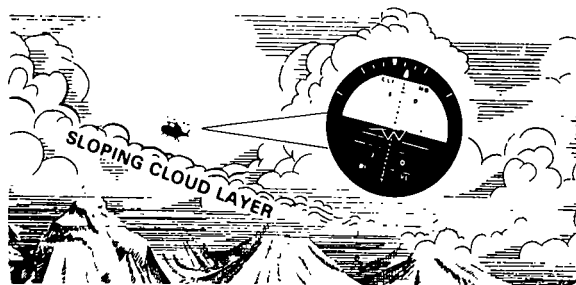


FIGURE 6-14. FALSE HORIZON ILLUSION.

Another illusion is when flying parallel to a line of clouds, there is a tendency to tilt away from the cloud.

☐ *Height Perception Illusion.* When flying over desert, snow, or water you experience an illusion of height above the terrain. This is due to the lack of visual references. To overcome this problem, it may be necessary to drop an object such as a smoke grenade on the ground before landing. Flight in an area when visibility is restricted by haze, smoke, or fog produces the same illusion of height perception.

☐ *Flicker Vertigo.* Much time and research have been devoted to the study of flicker vertigo. It has been demonstrated that a light flickering at a rate of between 4 and 20 cycles per second can produce unpleasant and dangerous reactions. Such conditions as nausea, vomiting, vertigo, and on rare occasions, convulsions and unconsciousness may occur. Fatigue, frustration, and boredom tend to intensify these reactions. The problem can be caused by the flickering of the rotating beacons as reflected against an overcast sky. When these conditions exist, you should turn the beacon lights off.

☐ *Fascination (Fixation) in Flying.* Fascination is said to occur when a pilot ignores orientation cues while focusing attention on another object or goal. Target hypnosis is a common type of fascination. The pilot becomes so intent upon hitting the target during a gunnery run that the pullup is delayed too long and the aircraft contacts the ground.

☐ *Structural Illusions.* Structural illusions are caused by heat waves, rain, snow, sleet, or other obscurants to vision. For example, a straight line may appear curved as seen through the heat wave of the desert, or a wingtip light may appear as a double light or in a different location as viewed during a rain shower.

☐ *Size-Distance Illusion.* The size-distance illusion results from staring at a point of light which approaches and recedes from the observer. In the absence of additional distance cues, accurate range estimation is extremely difficult. Instead of seeing the light advancing or receding, you may interpret the lights as expanding and contracting at a fixed distance. This illusion can be dispelled by using proper scanning techniques.

METEOROLOGICAL CONDITIONS AND NIGHT VISION

Although your flight may originate during conditions of clear skies and unrestricted visibility, meteorological conditions may deteriorate during the flight. Due to the reduced vision at night, the gradual encounter of clouds can easily go undetected. Inadvertent entry into clouds may occur without warning. At low

altitudes, the encounter of ground fog and haze can be expected. The loss of visibility can be a gradual deterioration or a sudden encounter. Because detection of adverse weather is difficult at night, you should maintain a constant awareness of changing conditions. The following conditions serve as indicators in the detection of adverse weather conditions at night:

☐ A gradual reduction in the light level will occur as cloud coverage increases, resulting in a loss of visual acuity and contrast of terrain features.

☐ Loss of visual contact with the moon and stars indicates that clouds are present. The degree to which the stars and moon are obscured determines the amount of cloud coverage.

☐ Shadows caused by clouds obscuring the moon's illumination can be detected by observing the varying levels of ambient light along the flight route.

☐ The halo effect that is observed around ground lights indicates the presence of moisture and the possibility of ground fog forming. As the intensity of these lights decreases, the moisture content is increasing.

☐ The presence of fog over water surfaces indicates that temperature and dewpoint are equal and that fog may form over the ground area.

AIRCRAFT LIMITATIONS ON NIGHT VISION

The design of Army aircraft degrades your ability to see outside the cockpit. To

minimize the loss of night vision due to aircraft shortcomings, you must properly prepare the aircraft for night flight. Consideration should be given to the following aircraft limitations.

☐ Windscreens reduce your ability to see outside the aircraft. To minimize the effect of windscreens on night vision they must be kept clean. Dirt, grease, bugs, and scratches must be removed from the windscreen prior to each night flight.

☐ The purpose of instrument lighting is to make the instruments easily readable to the pilot or crewmembers. Because visual acuity increases with illumination, this is best accomplished with a high level of instrument illumination. However, the level of illumination needed for optimum reading is not practical because it interferes with maximum dark-adaptation for the perception of dim objects outside the aircraft. Interior lights also reflected off the windscreen reduce outward visibility and are subject to detection by the enemy. To minimize the adverse effect cockpit lights have on night vision, all nonessential lights should be turned off and the light intensity of essential lights be reduced to the lowest usable level. To operate with minimum lights in the cockpit, each aircrewmember must know the location of the switches and controls within the cockpit. This is learned by conducting blindfold cockpit drills.

☐ The purpose of exterior lights is to identify the aircraft. However, when conducting terrain flight, the illumination from these lights degrades your night vision. To minimize the adverse effect of the exterior lights, you should turn off lights not required by regulation; and

operate the remaining lights in the dim mode or cover a portion of the light with tape.

☐ To properly prepare your aircraft for night flight, refer to the appropriate training circular for type aircraft. (See Appendix A, "References.")

PRINCIPLES OF NIGHT VISION

A thorough understanding of the anatomy of the eye and the techniques employed to overcome limitations is necessary in order to see in the dark. In summary, the principles for night vision are—

☐ Adapt to darkness before attempting to fly at night.

☐ Avoid bright lights after dark-adapting.

☐ Identify objects by total form.

☐ Use off-center vision when viewing an object.

☐ Do not stare; scan constantly and systematically.

☐ When available, use oxygen for conducting night flight above 4,000 feet pressure altitude.

☐ Avoid self-imposed stresses.

☐ Keep physically fit.

☐ Prepare the aircraft for night flight.

☐ Practice blindfold cockpit drill.

☐ Keep your windscreen clean, unscarred, and unscratched.

SECTION II

HEMISPHERICAL ILLUMINATION

DEFINITIONS

There are several terms associated with hemispherical illumination that you should become familiar with to better understand the subject.

□ *Ambient light*—Ambient light consists of all the prevailing light emanating from a natural or artificial source that illuminates a visual field of regard.

□ *Altitude*—Altitude is the position of the moon above the horizon as viewed from a specific point on the earth's surface. This measurement is expressed in degrees.

□ *Light level*—Light level is a measure of the intensity of illumination. This measurement is expressed in foot-candles.⁸ Factors which affect the light level are the percentages of moon illumination, the altitude of moon, and cloud coverage. The different light levels are *low*, *mid*, and *high*.⁸

□ *Phase angle*—The phase angle is the angle formed between the earth, sun, and moon (fig 6-15). The percentage of moon illumination is determined by the phase angle, e.g., the percentage of illumination for a phase angle of 90° is 50 percent.

□ *Zenith*—The zenith position of the moon is the highest point (altitude) it reaches for that day as viewed from a specific point on the earth's surface. The highest light level is experienced at the zenith position.

□ *Phases of the moon*—There are four phases of the moon—new moon, first quarter, full moon, and third quarter. The phase angle of the moon will determine the phase of the moon. See figure 6-15 for a visual description of the different phases of the moon.

□ *Greenwich mean time (GMT)*—Greenwich mean time is the basis of standard time throughout the world. The times depicted within hemispherical publications are GMT and must be converted to local time to determine when a particular condition will occur at your location.

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⁸ See notes in appendix C.

□ *Greenwich hour angle (GHA)*—The GHA is the longitude where the moon is located at a specific time, expressed in degrees. Angles of longitude between 1° through 180° place the moon in the Western Hemisphere and angles between 181° through 359° place the moon in the Eastern Hemisphere.

□ *Declination (Dec)*—"Dec" is the parallel of latitude where the moon is located at a specific time, expressed in degrees. When computing the moon altitude, north parallels of latitude are expressed as plus (+) and south parallels of latitude as minus (-).

SOURCE OF AMBIENT LIGHT

To gain maximum advantage of available ambient light, you must know the sources of ambient light and when the optimum conditions exist. The sources of ambient light are:

□ *Moon*. The greatest source of natural ambient light at night is the moon. Ambient light from the moon is greatest when the moon has the highest percentage of illumination and it is at the zenith position.

□ *Background illumination*. Natural background illumination consists of air-glow, aurora, starlight, gegenschein, noctilucent clouds, and zodiacal light. Ambient light received from these sources produces minimum light levels. These sources are most noticeable during the hours of darkness when the moon is not observable and when using night vision devices.

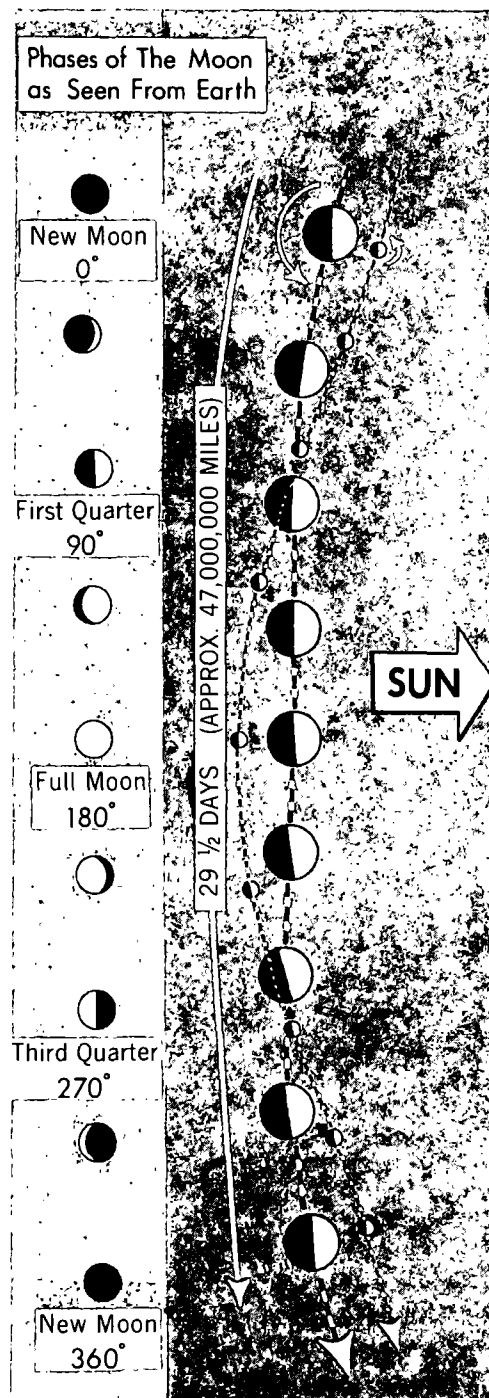


FIGURE 6-15. MOTION OF THE MOON.

TABLE 6-1. SOLAR TWILIGHT PERIODS.

TWILIGHT TYPE	END EVENING TWILIGHT	BEGINNING MORNING TWILIGHT
Civil (CT) -----	-6° (EECT)	-6° (BMCT)
Nautical (NT) -----	-12° (EENT)	-12° (BMNT)
Astronomical (AT) -----	-18° (EEAT)	-18° (BMAT)

Note. Minus degrees (e.g., -6°) represent the position of the sun in relation to the horizon.

□ **Artificial light.** Lights from cities, automobiles, and fires are sources of illumination. Normally, the ambient light produced is very small; however, the lights of a large metropolitan area will increase the light level around the periphery of the city. Greatest effect from these sources of light is achieved when an overcast condition exists.

□ **Solar light.** Ambient light from the sun is available for a period of time following sunset and before sunrise. Table 6-1 identifies the solar twilight period that occurs after sunset and before sunrise. Table 6-2 identifies the date and time sunset and sunrise occur. Sunset occurs when the crest of the sun rotates below the horizon. During the period of time from sunset to end of evening civil twilight (EECT), ambient light steadily decreases from a high light level to a mid light level. A comparison of table 6-2, "Sunrise and Sunset at Fort Rucker, Alabama," with table 6-3, "Civil Twilight at Fort Rucker,

Alabama," indicates that approximately 30 minutes will elapse between the two conditions. As the earth continues to rotate, the ambient light decreases from a mid light level to a low light condition at the end of evening nautical twilight (EENT). Table 6-4, "Nautical Twilight at Fort Rucker, Alabama," indicates that end of evening nautical twilight occurs at approximately 1 hour after sunset. Although solar light is available during the period from the end of evening nautical twilight to end of evening astronomical twilight (EEAT), the level of ambient light is not usable as viewed by the unaided eye. No ambient light is available from the sun after end of evening astronomical twilight or before beginning of morning astronomical twilight (BMAT). The available solar light prior to sunrise follows a reverse sequence to that experienced at sunset. Tables 6-2 through 6-4 identify when sunrise, beginning morning civil twilight, and beginning morning nautical twilight occur. Each of the tables is available through the US Air Force Weather Service.

TABLE 6-2. SUNRISE AND SUNSET AT FORT RUCKER, ALABAMA, 1978

DAY	JUL		AUG		SEPT		OCT		NOV		DEC	
	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET
01	0442	1851	0459	1839	0519	1807	0536	1728	0558	1654	0624	1640
02	0442	1851	0500	1838	0519	1806	0537	1727	0559	1653	0625	1640
03	0443	1851	0500	1837	0520	1804	0538	1726	0600	1653	0625	1640
04	0443	1851	0501	1836	0520	1803	0538	1725	0601	1652	0626	1640
05	0444	1851	0502	1835	0521	1802	0539	1723	0602	1651	0627	1640
06	0444	1851	0502	1835	0521	1801	0539	1722	0602	1650	0628	1640
07	0445	1851	0503	1834	0522	1759	0540	1721	0603	1650	0628	1640
08	0445	1850	0504	1833	0523	1758	0541	1720	0604	1649	0629	1640
09	0446	1850	0504	1832	0523	1757	0541	1718	0605	1648	0630	1640
10	0446	1850	0505	1831	0524	1755	0542	1717	0606	1648	0631	1641
11	0447	1850	0506	1830	0524	1754	0543	1716	0607	1647	0631	1641
12	0447	1849	0506	1829	0525	1753	0543	1715	0607	1646	0632	1641
13	0448	1849	0507	1828	0526	1752	0544	1715	0608	1646	0633	1641
14	0448	1849	0507	1827	0526	1750	0545	1713	0609	1645	0633	1642
15	0449	1848	0508	1826	0527	1749	0546	1711	0610	1645	0634	1642
16	0449	1848	0509	1825	0527	1748	0546	1710	0611	1644	0635	1642
17	0450	1848	0509	1824	0528	1746	0547	1709	0612	1644	0635	1643
18	0451	1847	0510	1823	0528	1745	0548	1708	0613	1643	0636	1643
19	0451	1847	0511	1822	0529	1744	0548	1707	0613	1643	0636	1643
20	0452	1846	0511	1821	0530	1743	0549	1706	0614	1642	0637	1644
21	0452	1846	0512	1820	0530	1741	0550	1705	0615	1642	0638	1644
22	0453	1845	0512	1819	0531	1740	0551	1704	0616	1642	0638	1645
23	0454	1845	0513	1817	0531	1739	0551	1703	0617	1641	0639	1645
24	0454	1844	0514	1816	0532	1737	0552	1702	0618	1641	0639	1646
25	0455	1843	0514	1815	0533	1736	0553	1701	0619	1641	0639	1646
26	0455	1843	0515	1814	0533	1735	0554	1700	0620	1641	0640	1647
27	0456	1842	0516	1813	0534	1733	0554	1659	0620	1640	0640	1648
28	0457	1842	0516	1812	0534	1732	0555	1658	0621	1640	0641	1648
29	0457	1841	0517	1810	0535	1731	0556	1657	0622	1640	0641	1649
30	0458	1840	0517	1809	0536	1730	0557	1656	0623	1640	0641	1650
31	0459	1839	0518	1808			0557	1655			0642	1650

Note. All times are central standard—Add 1 hour for central daylight time.

TABLE 6-3. CIVIL TWILIGHT AT FORT RUCKER, ALABAMA

LATITUDE 31°17'N
LONGITUDE 85°43'W

CENTRAL STANDARD TIME

NAUTICAL ALMANAC OFFICE
US NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

DAY	JAN		FEB		MAR		APR		AUG		SEPT		OCT		NOV		DEC	
	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM
1	615	518	610	543	546	605	508	626	433	705	454	631	512	553	533	519	557	506
2	615	519	610	544	545	606	506	627	433	704	454	630	513	551	534	519	558	506
3	616	519	609	545	544	607	505	628	434	703	455	629	513	550	535	518	559	506
4	616	520	608	546	542	607	504	628	435	702	456	628	514	549	536	517	600	506
5	616	521	608	547	541	608	503	629	436	702	456	626	515	548	536	516	600	506
6	616	522	607	547	540	609	501	630	436	701	457	625	515	546	537	516	601	507
7	616	522	606	548	539	610	500	631	437	700	458	624	516	545	538	515	602	507
8	616	523	606	549	538	610	459	631	438	659	458	622	517	544	539	514	603	507
9	616	524	605	550	537	611	458	632	438	658	459	621	517	543	539	514	603	507
10	616	525	604	551	535	612	456	633	439	657	459	620	518	542	540	513	604	507
11	616	525	603	552	534	612	455	633	440	656	500	619	518	540	541	512	605	507
12	616	526	602	552	533	613	454	634	440	655	501	617	519	539	542	512	605	508
13	616	527	602	553	532	614	453	635	441	654	501	616	520	538	543	511	606	508
14	616	528	601	554	530	614	452	635	442	653	502	615	520	537	544	511	607	508
15	616	529	600	555	529	615	450	636	443	652	502	613	521	536	544	510	607	509
16	616	530	559	556	528	616	449	637	443	650	503	612	522	535	545	510	608	509
17	616	530	558	556	527	616	448	638	444	649	504	611	522	534	546	509	609	509
18	616	531	557	557	525	617	447	638	445	648	504	609	523	533	547	509	609	510
19	615	532	556	558	524	618	446	639	445	647	505	608	524	532	548	509	610	510
20	615	533	555	559	523	618	444	640	446	646	505	607	524	530	548	508	610	511
21	615	534	554	559	522	619	443	640	447	645	506	605	525	529	549	508	611	511
22	615	535	553	600	520	620	442	641	447	644	507	604	526	528	550	508	611	512
23	614	536	552	601	519	620	441	642	448	642	507	603	527	527	551	507	612	512
24	614	536	551	602	518	621	440	643	449	641	508	601	527	526	552	507	612	513
25	614	537	550	602	517	622	439	643	449	640	508	600	528	526	553	507	613	513
26	613	538	549	603	515	622	438	644	450	639	509	559	529	525	553	507	613	514
27	613	539	548	604	514	623	437	645	451	638	510	558	530	524	554	507	613	514
28	612	540	547	605	513	624	436	646	451	636	510	556	530	523	555	506	614	515
29	612	541	547	605	512	624	435	646	452	635	511	555	531	522	556	506	614	516
30	611	542			510	625	434	647	452	634	511	554	532	521	557	506	615	516
31	611	542			509	626			453	633			532	520			615	517

This table may be used in any year of the twentieth century and within geographical boundary of the stated place with an error not exceeding 2 minutes and generally less than 1 minute. Add 1 hour for daylight saving time if and when in use.

OPEN FOR
FOLDOUT

TABLE 6-4. NAUTICAL TWILIGHT AT FORT RUCKER, ALABAMA

NAUTICAL ALMANAC OFFICE
US NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

LATITUDE 31°17'N
LONGITUDE 85°43'W

CENTRAL STANDARD TIME

DAY	JAN		FEB		MAR		APR		AUG		SEPT		OCT		NOV		DEC	
	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM	BEG AM	END PM
1	545	548	541	612	518	633	439	655	401	737	425	701	444	621	505	548	527	536
2	545	549	541	613	517	634	438	656	402	736	425	659	445	619	505	547	528	536
3	545	549	540	614	515	635	437	657	403	735	426	658	445	618	506	547	529	536
4	546	550	539	615	514	636	435	657	403	734	427	657	446	617	507	546	530	536
5	546	551	539	615	513	636	434	658	404	733	427	655	447	616	508	545	530	536
6	546	552	538	616	512	637	433	659	405	732	428	654	447	614	508	544	531	537
7	546	552	537	617	511	638	431	659	406	731	429	652	448	613	509	544	532	537
8	546	553	537	618	510	638	430	700	407	730	429	651	448	612	510	543	532	537
9	546	554	536	619	508	639	429	701	407	729	430	640	449	611	510	543	533	537
10	546	555	535	619	507	640	427	702	408	728	431	648	450	610	511	542	534	537
11	546	555	535	620	506	640	426	702	409	726	431	647	450	609	512	541	535	538
12	546	556	534	621	505	641	425	703	410	725	432	646	451	607	513	541	535	538
13	546	557	533	622	504	642	423	704	411	724	433	644	452	606	514	540	536	538
14	546	558	532	622	502	642	422	705	411	723	433	643	452	605	514	540	536	539
15	546	559	531	623	501	643	421	706	412	722	434	642	453	604	515	540	537	539
16	546	559	530	624	500	644	420	706	413	721	435	640	454	603	516	539	538	539
17	546	600	530	625	459	645	418	707	414	720	435	639	454	602	517	539	538	540
18	546	601	529	625	457	645	417	708	414	718	436	638	455	601	517	538	539	540
19	546	602	528	626	456	646	416	709	415	717	436	636	456	600	518	538	539	541
20	546	603	527	627	455	647	415	709	416	716	437	635	456	559	519	538	540	541
21	545	603	526	628	454	647	414	710	417	715	438	634	457	558	520	537	540	541
22	545	604	525	628	452	648	412	711	417	713	438	632	458	557	521	537	541	542
23	545	605	524	629	451	649	411	712	418	712	439	631	458	556	521	537	541	542
24	545	606	523	630	450	649	410	713	419	711	440	630	459	555	522	537	542	543
25	544	607	522	631	448	650	409	714	420	710	440	628	500	554	523	537	542	544
26	544	607	521	631	447	651	408	714	420	708	441	627	500	553	524	537	543	544
27	543	608	520	632	446	652	406	715	421	707	442	626	501	552	524	536	543	545
28	543	609	519	633	444	652	405	716	422	706	442	624	502	551	525	536	544	545
29	543	610	519	633	443	653	404	717	422	704	443	623	502	550	526	536	544	546
30	542	611			442	654	403	718	423	703	443	622	503	550	527	536	544	547
31	542	611			440	654			424	702			504	549			545	547

This table may be used in any year of the twentieth century and within geographical boundary of the stated place with an error not exceeding 2 minutes and generally less than 1 minute. Add 1 hour for daylight saving time if and when in use.

TABLE 6-5. PHASES OF THE MOON

1978
UNIVERSAL TIME

NEW MOON			FIRST QTR			FULL MOON			LAST QTR		
DAY	HR	MIN	DAY	HR	MIN	DAY	HR	MIN	DAY	HR	MIN
Jan 9	04	00	Jan 16	03	03	Jan 24	07	56	Jan 2	12	07
Feb 7	14	54	Feb 14	22	11	Feb 23	01	26	Jan 31	23	51
Mar 9	02	36	Mar 16	18	21	Mar 24	16	20	Mar 2	08	34
Apr 7	15	15	Apr 15	13	56	Apr 23	04	11	Mar 31	15	11
May 7	04	47	May 15	07	39	May 22	13	17	Apr 29	21	02
Jun 5	19	01	Jun 13	22	44	Jun 20	20	30	May 29	03	30
Jul 5	09	50	Jul 13	10	49	Jul 20	03	05	Jun 27	11	44
Aug 4	01	01	Aug 11	20	06	Aug 18	10	14	Jul 26	22	31
Sep 2	16	09	Sep 10	03	20	Sep 16	19	01	Aug 25	12	18
Oct 2	06	41	Oct 9	09	38	Oct 16	09	09	Sep 24	05	07
Oct 31	20	06	Nov 7	16	18	Nov 14	20	00	Oct 24	00	34
Nov 30	08	19	Dec 7	00	34	Dec 14	21	31	Nov 22	21	24
Dec 29	19	36	Jan 5	11	15	Jan 13	07	09	Dec 22	17	41

SUN-EARTH-MOON SYSTEM

The moon revolves eastward about the earth; but, because of its slower rotational speed as compared to the earth, it appears to move east to west. A complete revolution requires 29 days, 12 hours, 44 minutes, and 28 seconds. Because there is no difference in the period of revolution, the same side of the moon is always seen by an observer from the earth.

The orbital plane of the moon is tilted 5°9' toward the orbital plane of the earth. Because of this tilt, the moon's orbit is closer to the Northern Hemisphere during the winter months. As a result, ambient light is brighter in the winter than in the summer.

As the sun, earth, and moon rotate about their orbital planes, varying levels of ambient light are received from the moon.

This is caused by a constant change in the moon's phasing angle. Figure 6-15 depicts the relationship of the sun, earth, and moon as each celestial body revolves in its orbit. Because the rotation of the moon never changes and follows an exact time frame, timetables for each phase of the moon (new moon, first quarter, full moon, and last quarter) can be accurately computed for any year in the 20th century. Table 6-5, "Phases of the Moon," identifies when each phase of the moon will occur. Geographic location is not a consideration in computing the phase of the moon. The table identifies the date and time when each phase occurs in Greenwich mean time. At some time during a 24-hour period, this phase of the moon will be observed at every position on the earth; however, it will be at a later time than indicated on the table.

Because of the systematic movement of the sun-earth-moon, an accurate timetable

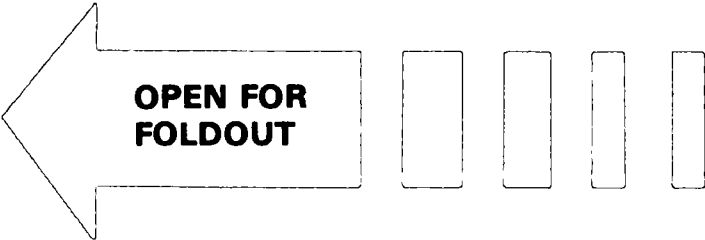


TABLE 6-6. MOONRISE AND MOONSET FOR 1978.

NAUTICAL ALMANAC OFFICE
US NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

LATITUDE 31°16'N
LONGITUDE 85°43'W

STANDARD MERIDIAN 90°00' WEST

	JUL		AUG		SEPT		OCT		NOV		DEC	
	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS
	H M	H M	H M	H M	H M	H M	H M	H M	H M	H M	H M	H M
1	02 01	15 44	02 59	16 55	04 20	17 32	04 56	17 17	06 39	17 54	07 31	18 23
2	02 43	16 35	03 50	17 38	05 14	18 07	05 53	17 53	07 42	18 43	08 31	19 26
3	03 27	17 25	04 41	18 18	06 09	18 42	06 51	18 32	08 43	19 37	09 27	20 30
4	04 14	18 12	05 33	18 55	07 04	19 17	07 50	19 14	09 43	20 35	10 17	21 34
5	05 02	18 57	06 26	19 31	08 00	19 54	08 50	19 59	10 40	21 36	11 04	22 39
6	05 53	19 38	07 20	20 06	08 58	20 33	09 51	20 49	11 32	22 39	11 45	23 42
7	06 45	20 17	08 14	20 40	09 57	21 15	10 50	21 43	12 19	23 43	12 25	
8	07 38	20 54	09 08	21 15	10 56	22 01	11 48	22 41	13 03		13 04	00 43
9	08 30	21 29	10 05	21 52	11 56	22 52	12 42	23 43	13 44	00 46	13 41	01 43
10	09 24	22 03	11 03	22 32	12 55	23 48	13 33		14 23	01 48	14 20	02 42
11	10 18	22 38	12 02	23 16	13 53		14 20	00 46	15 02	02 49	15 00	03 39
12	11 14	23 14	13 04		14 47	00 48	15 04	01 51	15 41	03 50	15 42	04 36
13	12 12	23 53	14 05	00 05	15 38	01 53	15 45	02 54	16 20	04 49	16 27	05 31
14	13 12		15 06	00 59	16 26	02 59	16 25	03 58	17 02	05 47	17 14	06 24
15	14 14	00 35	16 04	01 59	17 10	04 05	17 05	05 00	17 46	06 44	18 03	07 14
16	15 17	01 22	16 59	03 04	17 52	05 11	17 45	06 02	18 33	07 40	18 54	08 01
17	16 21	02 15	17 50	04 11	18 32	06 15	18 26	07 02	19 21	08 31	19 45	08 43
18	17 23	03 14	18 36	05 19	19 12	07 18	19 10	08 00	20 11	09 19	20 37	09 23
19	18 21	04 18	19 19	06 26	19 52	08 18	19 55	08 56	21 02	10 04	21 29	10 00
20	19 14	05 26	20 00	07 32	20 34	09 17	20 41	09 50	21 53	10 46	22 21	10 35
21	20 02	06 34	20 40	08 35	21 17	10 14	21 29	10 40	22 45	11 24	23 15	11 10
22	20 46	07 42	21 19	09 36	22 03	11 08	22 20	11 26	23 38	12 01		11 43
23	21 27	08 47	21 59	10 34	22 50	11 59	23 11	12 09		12 36	00 09	12 18
24	22 06	09 50	22 40	11 31	23 38	12 47		12 49	00 31	13 11	01 05	12 54
25	22 44	10 50	23 23	12 25		13 31	00 03	13 27	01 26	13 46	02 03	13 35
26	23 22	11 48		13 17	00 29	14 13	00 55	14 03	02 22	14 22	03 04	14 19
27		12 44	00 09	14 06	01 20	14 53	01 49	14 38	03 21	15 01	04 07	15 08
28	00 02	13 39	00 56	14 52	02 13	15 30	02 44	15 14	04 22	15 44	05 10	16 04
29	00 43	14 31	01 45	15 36	03 06	16 06	03 41	15 50	05 25	16 32	06 13	17 05
30	01 26	15 22	02 36	16 16	04 00	16 41	04 39	16 28	06 28	17 25	07 13	18 11
31	02 12	16 10	03 28	16 55			05 38	17 09			08 08	19 18

can be predicted for moonrise and moonset. Table 6-6, "Moonrise and Moonset," depicts the exact time moonrise and moonset will occur at Fort Rucker, Alabama. Computations for this table are based on a specific location, longitude, and latitude.

As the moon revolves on a vertical arc, the distance from a stationary point to the moon varies as it moves on its easterly orbit. This is referred to as the altitude of the moon. The lunar altitude is one of the most important factors influencing night illumination. For example, at low altitude, the vertical component of moonlight incident to a horizontal surface is small compared to that at high altitude. At low altitude, light is attenuated by a relatively long distance through the atmosphere of the earth. As the moon ascends in the sky, the distance through the atmosphere decreases and the vertical component of moonlight increases. The maximum ambient light level is achieved when the moon reaches the zenith position (directly overhead 90°).

LUNAR PHASES

During each phase of the moon, a different percentage of illumination occurs. Also, the time at which the moon rises and sets changes. To effectively use the ambient light provided by the moon, you must have an understanding of what to expect during each phase of the moon. Conditions experienced during each phase of the moon are:

□ *New moon.* The phase angle of a *new moon* begins at the 180-degree position and extends to the 90-degree position. It occurs when the moon rotates to a position

between the sun and earth (fig 6-15). Visual observation of the new moon at night is not apparent until the moon has reached the 173-degree position which takes approximately 2 days. The time required to complete this phase is approximately 8 days. During the first portion (4 days) of the phase, a low light level will prevail. As the phase progresses, the percentage of illumination increases and ambient light conditions will reach a high light level when the moon is approximately 30° above the horizon. Moonrise will occur during the late morning (a.m.) hours, and moonset during late evening (p.m.) hours. Approximately 35 percent of the moon will be illuminated at the end of the new moon phase. When night flight is conducted during this phase, it can be anticipated that a low light level will prevail most of the time. Best light conditions will exist shortly after darkness when the moon is at its highest altitude.

□ *First quarter.* The phase angle of the moon at the *first quarter* begins at the 90-degree position. The percentage of illumination of the moon at the beginning of the phase will be approximately 50 percent and increase in coverage until slightly less than 100 percent of the apparent disk is illuminated. Approximately 7 days are required to complete the first quarter phase. When the moon reaches a point 15° above the horizon, a mid light level will prevail and gradually increase to a high light level. Moonrise occurs during the early afternoon (p.m.) hours. Moonset changes from midnight to the early morning (a.m.) hours. The best time for conducting flight normally will be just after



sunset. Due to the high light intensity of the moon, flight should be avoided in the direction of the moon when its altitude is low on the horizon.

☐ *Full moon.* A full moon occurs when the sun, earth, and moon are aligned at the zero-degree position (fig 6-15). At this time, the moon is radiating its greatest illumination. The full moon phase begins when 100 percent of the disk is illuminated and ends when approximately 65 percent of the moon is visible. The full moon phase lasts approximately 7 days. A high ambient light level prevails when the moon is approximately 15° above the horizon. During the early part of the phase, moonrise occurs just before nautical twilight and progressively increases into the mid evening (p.m.) hours. Moonset will occur during the mid morning (a.m.) hours. The optimum time for conducting flight will be shortly after midnight.

☐ *Last quarter.* The phase angle of the moon at the last quarter is very similar to the first quarter but in reverse sequence. It begins when approximately 55 percent of the moon is visible and ends when 2 percent or less is visible. The last quarter will normally last approximately 7 days. The ambient light level will decrease from a high light level down to a low light level. Moonrise will occur during the early morning (a.m.) hours. The most desirable time for conducting night flight is just prior to BMNT. Moonset occurs during the early afternoon (p.m.) hours.

HEMISPHERICAL PREDICTION

Night aviation operations should be conducted when the highest level of ambient light is available in the area where the mission will be performed. To determine when the optimum conditions would exist, a series of mathematic calculations

must be performed. Normally, it is the responsibility of the operations officer to develop a light level calendar for use by aviators in planning their flights. These calendars could be prepared months in advance. The procedures for developing the light level calendars as depicted in fig 6-16 are contained in appendix D.

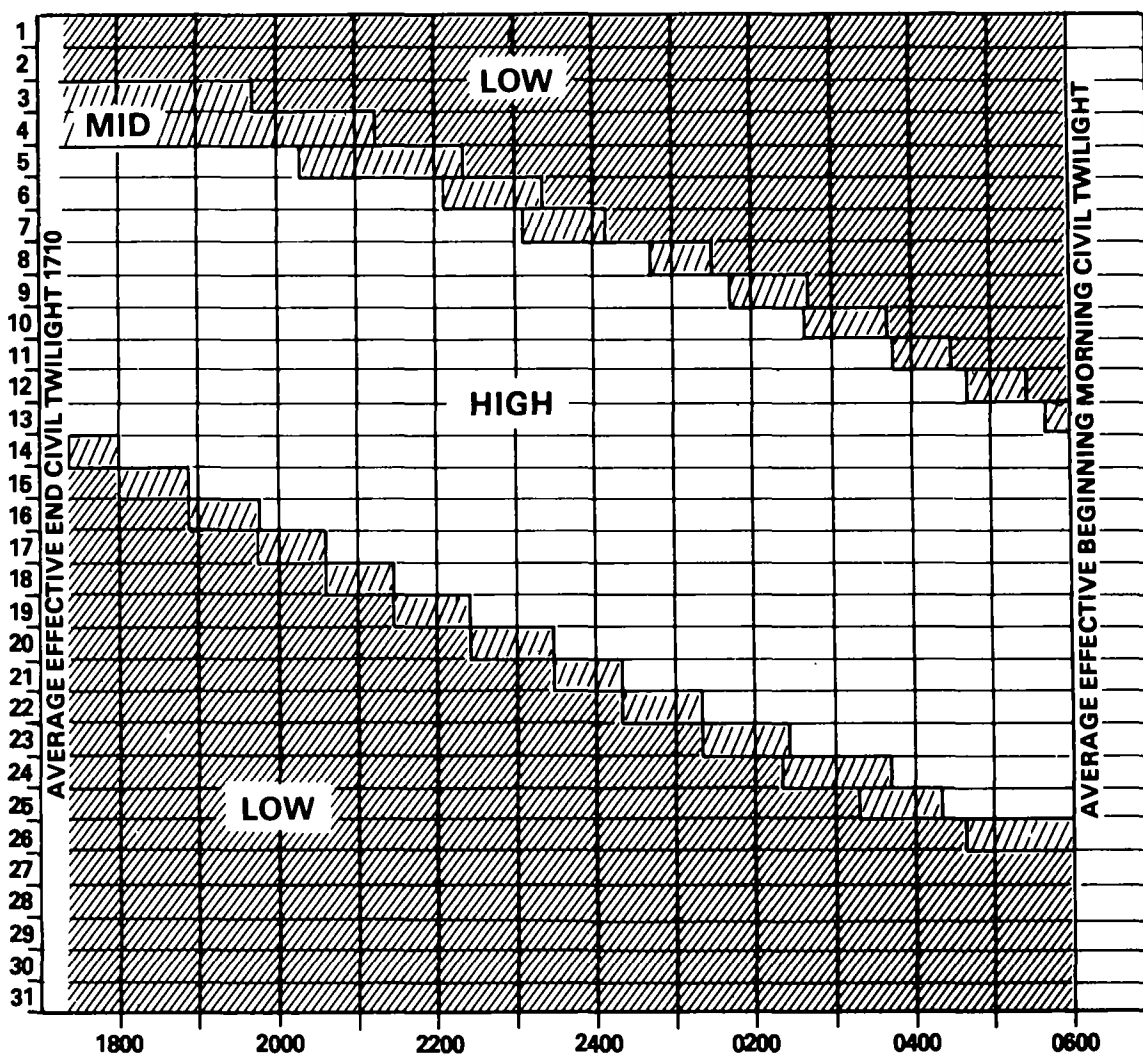


FIGURE 6-16. LIGHT LEVEL CALENDAR (DECEMBER 1978).

METEOROLOGICAL CONSIDERATIONS

Hemispherical illumination data referred to in this section does not consider the effects of atmospheric conditions. Because varying meteorological conditions exist, the light level cannot always be accurately predicted. An awareness of these limiting factors will assist in evaluating the available ambient light. Meteorological conditions which restrict hemispherical illuminations are discussed below.

☐ All clouds significantly reduce hemispherical illumination. A layer of cirrostratus or altostratus clouds will reduce the light level by as much as one-half. Heavier cumulonimbus clouds, usually associated with a thunderstorm, can reduce ambient light by a factor of ten. The degree of absorption of solar energy by clouds is unknown; therefore, a common factor cannot be applied to each condition of cloud coverage. Considerations which should be used in evaluating the reduced ambient light caused by cloud coverage are:

- Amount of cloud coverage (scattered, broken, or overcast).

- Density of clouds (thin).

☐ Water vapor reduces transmission of moonlight through the atmosphere. During periods of high moisture content, ambient light is significantly reduced.

☐ Any restriction to visibility such as fog, dust, haze, or smoke reduces hemispherical illumination. These conditions are more pronounced at lower altitudes and intensify as temperatures decrease.

SECTION III

TERRAIN INTERPRETATION

CUES FOR VISUAL RECOGNITION

The observer's ability to detect a natural or manmade feature at night depends primarily on the following factors:

□ **Object Size.** Because visual acuity decreases at night, the ability of the eye to perceive small objects becomes difficult if not impossible. Large structures and terrain features such as churches, water towers, and rivers are more easily recognized during hours of darkness. A small object such as an observation helicopter is difficult to identify because it becomes lost in the background (fig 6-17). To perceive small features you must view the area of concern several times. A shorter viewing distance will also aid in visual recognition.

□ **Object Shape.** A natural or manmade object can be identified at night by the shape or silhouette it forms (fig 6-18). Familiarization with the architectural design of buildings will assist in recogni-

tion of structures at night. When shape is used to identify an object it may be necessary to move to a different position in order to obtain a different viewing perspective. For example, a tank which could not be recognized from the front may be easily recognized when viewed from the side. Shape of terrain features also provides a means of identification at night. Open fields which are shown on the map as triangular shaped may provide positive identification when viewed from the air. Landmarks such as a bend in the river or a prominent hilltop provide a distinct shape which aids in terrain interpretation at night.

□ **Contrast.** Identification of manmade or natural features by contrast is dependent upon the available *ambient light*, the *color* and *texture* of the object being viewed, and its background (fig 6-19).

○ The *ambient light* level will affect the degree of contrast that exists between objects. The higher the light level, the greater the contrast. Each object possesses a different reflectance due to the nature of its reflective surface. As the ambient light increases, more light is reflected and shades become more recognizable. Objects with a poor reflective surface appear black during low light levels and dark gray during a high light level. Objects or terrain features which possess good reflective quality will appear gray and become progressively lighter in color as the ambient light increases.

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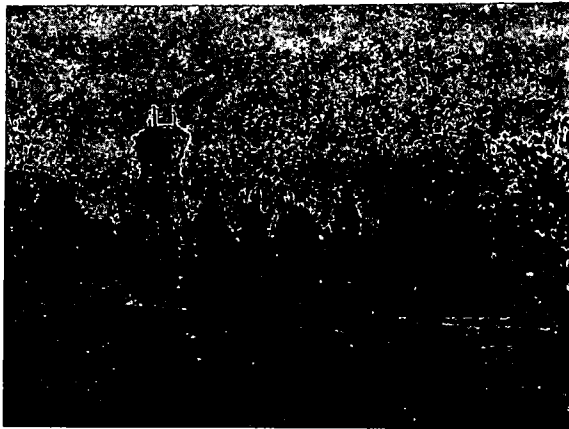


FIGURE 6-17.
IDENTIFICATION BY OBJECT SIZE.

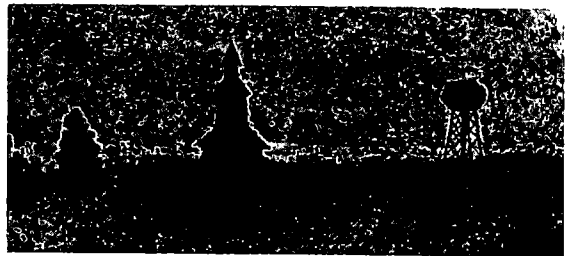


FIGURE 6-18.
IDENTIFICATION BY OBJECT SHAPE.

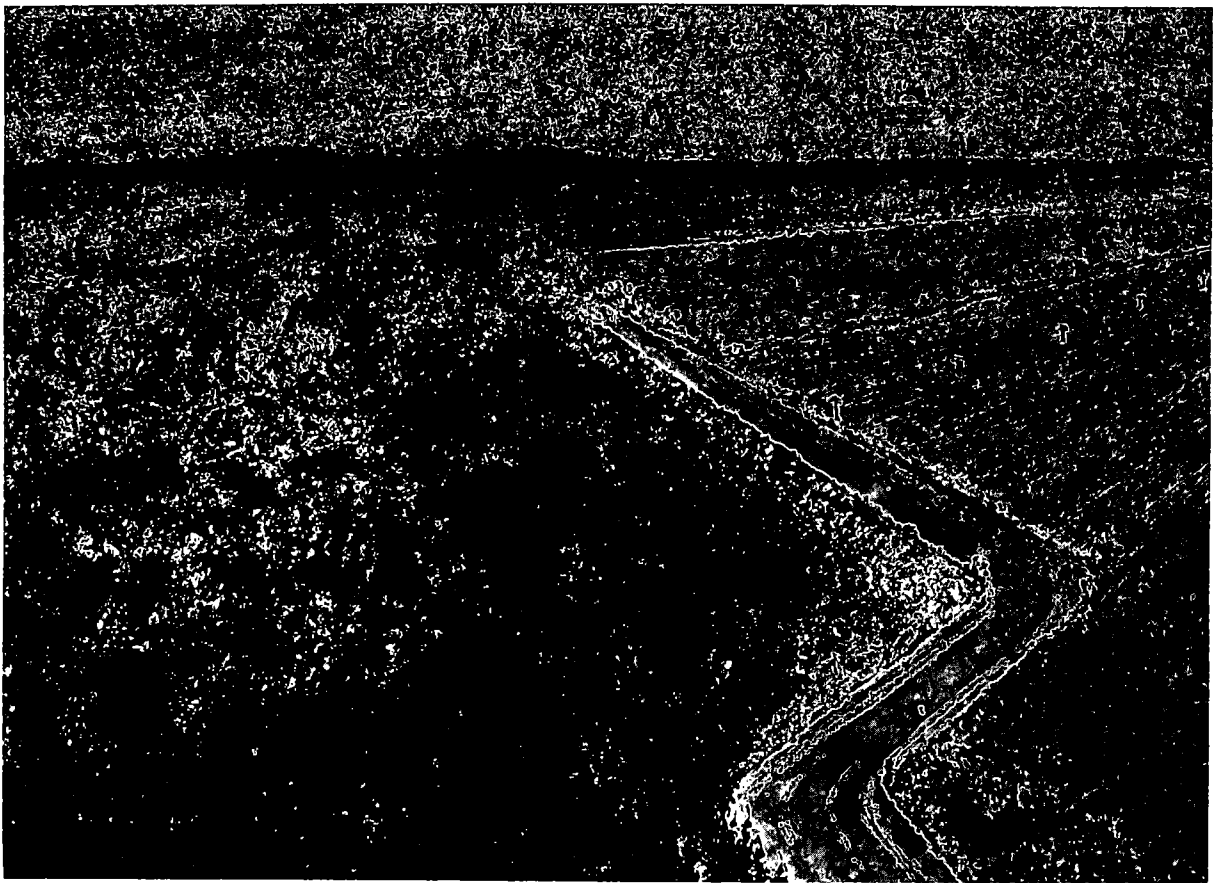


FIGURE 6-19. IDENTIFICATION BY OBJECT CONTRAST.

◎ The *color* and *texture* of a manmade or natural feature determines its reflective quality. An unplowed field with no vegetation provides an optimum reflective surface. Areas which are covered with dense vegetation provide the worst condition of reflectivity. Seldom is terrain encountered where the extreme of both cases will be found. Knowledge of the reflective quality of a feature will aid in identification by contrast. Manmade and natural features which are most affected by contrast are—

▪ *Roads.* Dirt roads provide excellent contrast between the surrounding terrain and its surface. Contrast is more pronounced where the road is cut through heavily forested areas. Normally, a dirt road will vary in soil texture from the soil adjacent to the road and is recognizable during mid light level conditions. Asphalt roads are difficult to identify because the dark surface absorbs available light, therefore, the contrast between the road and surrounding terrain is poor. The light color of concrete highways provides an excellent reflective surface and is easily identified during most light level conditions.

▪ *Water.* Bodies of water provide very little contrast against a landmass during low light conditions. When viewed from the air, lakes or rivers appear as dark gray in color. As the light level increases, water begins to change in color, contrast increases, and reflected moonlight can be easily detected. When a surface wind exists, the reflection off the water is intensified by the ripples on the surface which further aid in identification. Bodies

of water are more easily recognized when viewed from an angle rather than directly overhead.

▪ *Open fields.* Contrast is very poor in fields that are covered with vegetation. Most crops are of dark color and tend to absorb light. During the harvest or dormant time of the year, the color of the vegetation changes to a lighter color and contrast improves. A recently plowed field may be void of vegetation; however, because of the coarse texture of the soil which is caused by plowing, light is absorbed and very little is reflected.

▪ *Forested areas.* Heavily forested areas do not reflect light and appear as dark areas at night. Excellent contrast exists between an open field and a forested area that normally surrounds an open field. If flight is conducted over heavy vegetation, difficulty will be experienced in identifying objects and terrain features because of the lack of contrast.

▪ *Desert.* The light color of the soil and sparse vegetation growth which are characteristic of desert terrain provide the best condition of detecting objects and prominent terrain features by contrast. Military targets are easily recognized on the desert because of the contrast between dark and light objects. Frequently, camouflage is used to avoid detection. Mountain ranges which abruptly rise from the desert floor can be easily identified because of the dark color of barren mountains as contrasted against the light color of the desert floor.

FACTORS AFFECTING TERRAIN INTERPRETATION

Your ability to use the cues for terrain interpretation is affected by:

□ *Ambient Light.* Reduced light level at night decreases visual acuity which restricts the distance at which an object can be identified. Terrain interpretation by size, shape, and contrast becomes more difficult as the light level decreases. To improve visual interpretation slower air-speed must be flown.

□ *Viewing Distance.* Because the viewing angle becomes smaller as the distance from the object increases, objects which are large in size and distinctive in shape may become unrecognizable if viewed from a great distance at night. This, combined with poor range estimation at night, can lead to misjudgment of size. Also, objects lose form as the viewing distance increases. A church building viewed at a close distance at night will appear as a large structure with a distinctive high roof; however, when viewed at a great distance it may resemble a family dwelling. This phenomenon occurs when viewing military targets or terrain features at great distances (fig 6-20). The distance at which interpretation of an object becomes unreliable is also dependent upon the ambient light level. An object that can be identified by its shape and size at a distance of up to 1,500 meters during a high light condition might be unrecognizable at 500 meters during a low light condition.



FIGURE 6-20. IDENTIFICATION BY OBJECT
VIEWING DISTANCE.

□ *Flight Altitude.* Your ability to identify manmade or natural features progressively decreases as the flight altitude increases. This condition is affected by all levels of ambient light. As the flight altitude increases, contrast between features becomes less distinguishable and tends to blend together. Also, terrain definition becomes less recognizable and difficulty is experienced detecting altitude changes. Due to the change of the viewing angle and the distance which the object is being viewed, the apparent shape of an object will be different than the true perspective.

Terrain definition becomes more recognizable and contrasts improve when the helicopter is flown closer to the ground. This allows for better recognition of manmade and natural features which improve your navigational capability. Recognition of features by silhouetting an object against the skyline can be used at low altitude. The visual perspective changes at low altitudes in that the area

which can be viewed is smaller. The apparent rate of speed increases, reducing viewing time. Airspeed may have to be reduced to permit more accurate terrain interpretation.

□ *Effects of Moon Altitude.* Terrain interpretation is more difficult when the moon is low on the horizon. This is due to the lower light level that prevails and the shadows that form on the backside of features. If low level flight is conducted toward the moon when it is low on the horizon, glare may be experienced. This condition will cause distortion of vision and possible loss of dark-adaptation. When the moon is low on the horizon, recognition of objects or terrain features that are visible along the skyline is improved.

The higher the altitude of the moon, the greater the ambient light condition. An increased ambient light level improves visual acuity and contrast. Shadows which cause distortion of objects and terrain features and loss of ambient light do not occur. The best conditions for visual interpretation for any phase of the moon exist when the moon is at its highest altitude.

□ *Visibility Restriction.* During conditions of reduced visibility, the ambient light level is reduced which causes a loss of visual acuity. The onset of visibility restrictions will normally be gradual. Initially, the visual range at which a manmade or natural feature can be identified is reduced, followed by a loss of terrain definition. As visibility becomes more restrictive, night vision may become impaired to the extent that low level flight should be discontinued.

□ *Effects of Terrain.* The nature of the terrain will determine the amount of light that is reflected from the earth's surface. *Desert, rolling terrain, and mountain* conditions are examples of the different types of terrain and how light reflectivity is affected.

• *Desert.* The texture and color of the soil of the desert floor provide optimum reflectivity of available ambient light and identification of objects by contrast. Manmade or natural features that appear on desert floor are easily recognizable. Flight altitude is normally lower, thus improving terrain recognition. Visibility restrictions are not common; however, during conditions of high winds blowing sand will significantly restrict terrain interpretation.

• *Rolling Terrain (Heavy Vegetation).* Terrain interpretation is difficult over rolling terrain (heavy vegetation) due to the lack of recognizable terrain features. Contrast is good between forested areas and open fields. Rivers and terrain features which give distinct changes in elevation from surrounding terrain provide the most recognizable natural landmarks for navigation. Dirt roads and farm structures provide the most distinguishable manmade features. To improve terrain interpretation, airspeed must be slower. Flight altitude will normally be higher due to reduced capability to detect obstructions.

• *Mountains.* Terrain identification can be accomplished best where rapid changes in elevation occur such as mountainous areas. Silhouetting ridgelines or other objects with vertical features against the skyline enhance recognition of objects and terrain features. Decreased ambient

light can be anticipated in valleys and on the backside of mountains when the moon is low on the horizon. Contrast is poor where heavy growth of vegetation exists. Mountains that are barren reflect ambient light and contrast is improved. During high light conditions, navigation is made easier by the abundance of recognizable terrain features. Airspeed, however, will normally be slower in mountainous regions because of rapidly changing terrain which requires corresponding altitude changes.

□ *Effects of Seasons.* The seasons of the year affect the amount of ambient light that is reflected from the earth's surface. The following conditions are examples of the different seasons and how light reflectivity is affected.

● *Winter.* Contrast improves during the winter because farm areas are barren of vegetation. Contrast is also improved where snow covers the ground. The light color of the snow compared with the dark color of structures and heavy forested areas enhances visual interpretation.

The loss of foliage on deciduous trees and plants during the winter improves recognition of ground features such as small streams. Plants and grass which cover open fields change in color and improve the contrast between open fields and evergreens. Because a tree is barren of foliage, less light is reflected. As a result, greater difficulty will be experienced in detecting trees. This condition induces a safety hazard and may require that the helicopter be flown at a higher altitude.

The orbital path of the moon is closer to the earth during the winter. At this time,

ambient light level is higher than at any other time of the year. This improves visual acuity which enhances terrain interpretation.

It can be anticipated that during the winter there will be an increased number of days when cloud coverage and restricted visibility will prevail. Both conditions significantly reduce the available ambient light which has the effect of decreasing visual acuity and increasing the problem of terrain interpretation.

Where conditions of extreme cold and heavy buildup of snow exist, manmade and natural terrain features may be hidden. A road intersection which provides a good navigation checkpoint may be obscured by a snowdrift. Identification must be made by association with other objects or terrain features. A powerline, a fence line, or a cut through a forested area aids in locating the road intersection. Small rivers and lakes that are indicated on the map may be frozen and covered with snow and may not be recognizable. Positive identification can only be made by associating the relative position with other terrain features such as a depression, a tree line, or any other distinguishable terrain feature.

● *Summer.* During the summer, identification of objects and terrain features by contrast is less effective as compared to the winter season. This is caused by the increased amount of vegetation in open fields and a new growth of foliage on deciduous trees and plants. Small rivers and streams will be difficult to recognize. Military targets may also be unrecognizable when located in or near forested areas.

SECTION IV

NIGHT FLIGHT TECHNIQUES

CHARACTERISTICS
OF NIGHT FLIGHT

The techniques learned in day flight can be applied to night flight; however, due to reduced vision different cues must be used for determining relative position and speed of the helicopter in relation to the ground. Also, when airborne, more reliance is placed on flight instruments to maintain a safe flight attitude. The characteristics of

each helicopter peculiar to the maneuvers discussed are not covered. Normally, only general techniques applicable to all helicopters are identified. When specific techniques are discussed, reference will be to the UH-1.

LIMITATIONS

To effectively operate at night, you must know the limitations that are encountered at night and how to cope with each condition. Limitations that will be encountered at night are—

☐ Visual reference outside the aircraft will be limited. As a result, difficulty will be experienced in detecting relative movement of the helicopter forward and laterally during the hover. Also, the hover altitude is difficult to estimate. Movement of the helicopter over the ground is difficult to detect because terrain features at night tend to blend into one solid background. The degree of difficulty that is experienced is dependent upon the ambient light level and the altitude of the aircraft. Because movement is difficult to detect, rate of closure toward objects far away and close in cannot be accurately ascertained. When visibility is good, lights can be identified at great distances, giving a false impression of how far the light is from the helicopter. Ground track is difficult to determine due to the lack of references.

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☐ During daylight hours, equipment, instruments, control switches, etc., within the cockpit can be easily recognized. At night these same items are very difficult to locate. You must be capable of identifying every item within the cockpit in complete darkness. This degree of proficiency is essential to insure that the proper control switch is activated when applying emergency procedures. Also, navigational publications and flight equipment are hard to find in the cockpit at night. Procedures should be developed which standardize the location of these items to insure positive identification when they are needed.

☐ Visual references which provide checkpoints for positive identification during the day are difficult to see at night. The best visual aids for night navigation at altitude are objects which emit illumination (e.g., towers with obstacle lights, airport beacons).

☐ Because visual references are limited at night, the common tendency is to overbank the helicopter and raise or lower the nose in a turn when the maneuver is being performed by visual reference or pilot senses. These control inputs may result in an unusual attitude or induced vertigo. Reference to primary flight instruments (e.g., airspeed and altitude) should be included in your cross-check when performing a night maneuver above terrain flight altitudes. Visual flight becomes more demanding when it is conducted over sparsely inhabited areas where a reduced number of ground lights are found. Also, as the altitude above the ground increases, visual references become less effective and more reliance must be placed on the use of instruments.

☐ Reduction in visual references may cause you to concentrate more attention on a single light or a group of lights in a concentrated area. This condition induces illusions and may cause vertigo. To eliminate this unsafe phenomenon, avoid staring at a single light. Landing areas should always be lighted with two or more lights that are widely separated.

☐ At night, adverse meteorological conditions may be encountered unexpectedly. Ground visibility restrictions and clouds may form below the flight altitude. When ground references become obscured, you should anticipate that a layer of clouds or fog is below your flight altitude. Clouds at the same flight level are difficult to identify and are not usually detected until entering instrument meteorological conditions (IMC). Procedures to be followed upon entry into IMC must be established prior to conducting night flight.

☐ When fully night-adapted, the eyes become extremely sensitive to light. Exposure to a light source will cause partial or complete loss of night vision. Caution must be taken to avoid exposure to light sources, both outside and inside the aircraft.

☐ Crew mental and physical fatigue occurs sooner in night flying than in day flying. When possible, night training periods should not exceed 1.5 hours. Flying more than 1.5 hours produces mental and physical fatigue which causes a marked deterioration of individual performance and efficiency. This condition produces poor coordination, slower reaction time, and reduction of night-vision capability.

FACILITY REQUIREMENT

Consideration must be given to improving the flight facilities where night training is conducted. In the past, these facilities were satisfactory for the type of training that was being conducted; however, the training required to operate in a high threat environment necessitates that flight facilities be improved. The following factors should be considered (by commanders) in preparing the facilities and providing equipment for night training.

☐ Extinguish nonessential lights on flight line.

☐ Install red light in briefing rooms.

☐ Provide takeoff and approach routes away from illuminated areas.

☐ Mask or filter headlights of maintenance vehicles and fuel trucks.

☐ Park aircraft to be used for night training as far away from lighted areas as possible.

☐ Provide hover lanes that will allow the aircraft to be hovered without the use of landing lights.

☐ Provide variable intensity runway lights that will permit the reduction of light intensity based on the light level and student proficiency.

☐ Provide filters for tactical landing lights when the aircrew is wearing night vision goggles.

☐ Provide aircraft for training when the optimum light levels prevail.

☐ Where the basefield cannot be prepared as required for night flight training, a tactical landing site should be available where the aircraft can be landed and prepared for night flight training.

AIRCRAFT PREPARATION

The normal configuration of an aircraft does not require any special preparation for day flight; however, unless it is prepared for night flight, your night vision will be degraded. To determine the requirements for preparing your aircraft for night flight, refer to the specific training circular (TC) in the "preparation for night flight" series. Generally speaking, the requirements for preparing your aircraft for night flight are:

☐ Set all rheostats to the lowest usable level.

☐ Extinguish nonessential lights such as the overhead console and center pedestal.

☐ Dim lights that are not controlled by rheostats through the use of tape or red acetate.

☐ Identify the source of any reflection on the windscreen and extinguish the light or cover it with tape.

☐ Turn off the anticollision light as stated in the appropriate TC.

☐ Place special emphasis on the cleanliness of the windscreen.

☐ Use minimum light intensity for interior lighting.

☐ Never use a white light after night adapted.

☐ Standardize the console configuration of like category of aircraft.

NOTE: The above recommendations for preparing the aircraft for night flight are applicable for unaided vision. If flight is to be conducted using the night vision goggles, even greater restrictions of the aircraft lighting system are required.

PERSONAL PREPARATION

The proper preparation of the aircraft and ground facilities for night flight will contribute significantly to the success of a night mission; however, the mission may fail unless you are physically and mentally prepared to participate in night flight. To insure your readiness, the following guidelines should be followed:

- ☐ Keep physically fit.
- ☐ Eat a nutritionally balanced diet.
- ☐ Obtain adequate rest.
- ☐ Avoid self-medication.
- ☐ Avoid the use of tobacco and alcohol.
- ☐ Dark-adapt at least 30 minutes prior to flight.
- ☐ Avoid all bright lights after dark-adaptation.
- ☐ Learn and use the principles of night vision.

☐ Avoid bright sunlight during the day.

☐ Participate in frequent night flight training.

PATHFINDER SUPPORT

When performing night approaches to a tactical landing site, a qualified pathfinder should be located in the landing zone. Pathfinders set up the tactical landing site and upon request, provide the following information:

- ☐ Flow of traffic.
- ☐ Landing heading.
- ☐ Obstacles along the approach path.
- ☐ Field elevation.
- ☐ Wind direction and approximate velocity.
- ☐ Landing zone (LZ) hazards.
- ☐ Number of aircraft in the traffic pattern.
- ☐ Suggested traffic pattern altitude.
- ☐ Location of parking area in relation to touchdown point.

Pathfinders who are used in support of night operations should be included in all briefings prior to the missions being flown.

FLIGHT BRIEFING

Thorough preflight planning is essential for night flight. The following are the minimum subjects that should be discussed during a night preflight briefing.

☐ In-depth weather briefing for the entire flight period, to include winds, sunset, moonrise, percent moon available and the ambient light level during time of flight.

☐ Visibility restrictions (e.g., smoke, haze, fog) during the flight period.

☐ Review the hazard map for obstructions that are located in the training area.

☐ Discuss the traffic pattern to be flown, maneuvers to be performed, airfield lighting, and aircraft lighting.

☐ Discuss the mission/training maneuvers to be performed.

☐ Aircrews should be briefed to make a go-around anytime the approach feels uncomfortable. The reason for the uncomfortable approach should be discussed. If the crewmembers notice the effects of fatigue, the flight period should be terminated.

☐ At the conclusion of the mission, a thorough debriefing should be conducted. Included in the debriefing should be lessons learned, problems which arose during the flight, recommended solutions to these problems, and the individual's exact feelings about the mission or maneuvers being performed at night.

CREW DUTIES

Specific crew duties are designed to insure the teamwork necessary to conduct night flight. In a training environment, this sharing of duties should not relieve the instructor of his overall responsibilities. The following examples do not limit the duties which can be assigned to crewmembers, but insure that crew duties are designated during the preflight briefing and understood by each member.

Duty	Person Flying	Person Not Flying
◉ Before-takeoff check	--	X
◉ Before-landing check	--	X
◉ Aircraft control	X	--
◉ Outside orientation	X	X
◉ Radio calls	X	X
◉ Perform checks (airspeed, altitude, RPM, rate of descent, engine and transmission instruments, etc.)	X	X
◉ Approach angle, rate of closure, etc.	X	X
◉ Tuning radios	--	X

COMMON PHRASEOLOGY

Another factor in planning for night flight is to develop common phraseology (terminology) between the aircrew members. For example, if the copilot advises the pilot the next landmark will be a river, the pilot may not recognize the body of water he identified as a stream. This phraseology can vary and will be dependent upon the type aircraft flown. Unit standing operating procedures (SOP) should be developed identifying standard terms to be used by the aircrews during flight.

PREFLIGHT

Preflight inspection should be conducted during daylight hours when possible. If the preflight inspection is conducted at night, a flashlight with a white lens should be used to supplement the available lighting. If a red lens is used, oil and hydraulic leaks are not detectable. Adequate time should be allowed to dark-adapt after the preflight. The night preflight checklist is identical to daylight inspection; however, due to limitations of night vision, more time will be required to complete the preflight.

During the preflight, the windscreens should be checked to insure that each one is thoroughly cleaned and relatively free of scratches. Windscreens that are scratched may be satisfactory for day flight but not acceptable for night flight. Aircraft equipped with glass windscreen are more desirable for night flight.

Prior to conducting the preflight, an evaluation of writeups on the DA Form

2408-series should be made to determine if there are any discrepancies which would restrict the aircraft from night flight. Discrepancies which would make the helicopter nonoperationally ready for night flight may be acceptable for day flight (e.g., windscreens scratched, inoperative lights).

USE OF LIGHTS

To standardize the use of aircraft lights and to minimize the adverse effect of these lights on night vision, the following operating procedures for aircraft lighting are recommended.

☐ *Position Lights.*

- During runup, operate the position lights in the FLASH BRIGHT mode.

- Turn position lights on to the STEADY BRIGHT mode prior to takeoff.

- During formation flights operate with the position lights in the STEADY DIM position.

- If the anticollision light is inoperative when in flight, operate the position lights in the FLASH BRIGHT mode.

- During shutdown, operate the position lights in the FLASH BRIGHT mode. Lights should remain on until the rotor blade is stopped and tied down.

NOTE: The navigation and fuselage lights illuminate the cockpit and also create a halo around the fuselage.

These conditions cause a degradation of night vision. To minimize this problem, you should either turn the navigation lights off, operate in the dim mode, or tape all or part of the lights. In combat, the navigational lights would be turned off; however, when conducting training within the Continental United States (CONUS), the navigational lights must be on during the periods from sunset to sunrise. Any modification to the red or green navigational lights require approval from the Federal Aviation Agency (FAA). Commanders have the authority to tape or turn the white fuselage lights off.

☐ *Cockpit Lights.*

- During prestart checks, cockpit lights should be adjusted to the lowest intensity level that will allow you to read the instruments. The red dome light may be used to assist in illuminating the cockpit and the cabin area. The dome light should be turned off before hovering the helicopter.

- For nontactical flights above 500 feet, the instrument and panel lights may be illuminated. As the ambient light level decreases from a twilight condition to darkness, the intensity of the cockpit lights should be reduced. The intensity should be adjusted to the lowest readable level. Reflection of interior lights off the windscreen is minimized by reducing the level of intensity of the cockpit lights.

- When conducting night flight by reference to instruments, the cockpit lights will be adjusted to a higher intensity. A

loss of night vision will occur under these conditions. Prior to landings, cockpit lights should be dimmed to enhance your night-vision capabilities for outside references during the landing.

- When conducting night terrain flight, interior lights will be adjusted to the lowest usable light intensity. If the light intensity of a specific light is too bright, cover it with acetate or tape. Lights not required for safe flight, e.g., overhead console lights and the pedestal panel lights, should be turned off.

- For helicopters equipped with a BRIGHT-DIM switch which controls the intensity of the caution panel warning lights, the DIM mode should be selected for night flight.

- The map light may be used to supplement the available light in the cockpit. Normally, it is used by the navigator/copilot to view maps. During the preflight, these lights should be checked to insure that the red lens mode has been selected. Also the variable rheostat should be checked to insure that it is turned to the OFF position.

- In addition to the aircraft interior lights, a flashlight may be used to provide illumination within the cockpit. When using the flashlight, a red lens filter should be installed.

☐ *Anticollision Light.*

- For nontactical operations, the anticollision light should be turned on prior to starting the engine. This light will remain on until the rotor blade stops turning during shutdown.

- When conducting nontactical flight formations, the anticollision light will be turned off with the exception to the trail helicopter.

- Upon entry into instrument meteorological conditions, the anticollision light should be turned off. Operation of the anticollision light during these conditions tends to induce distraction and disorientation.

- During the conduct of tactical operations, the anticollision light will be turned to the OFF position.

NOTE: Commanders may authorize anticollision lights to be turned off if the procedure is clearly defined in the unit SOP. The anticollision light should be on when the aircraft is en route to the training area or when the density of the aircraft requires its use for safe operation.

☐ *Landing Light/Searchlight.*

- The landing light or searchlight is normally turned on during all takeoffs and landings from established airfields when conducting nontactical training. The landing light or searchlight may be used when hovering to and from the parking spot. Caution must be taken to minimize the loss of night vision when flight is to be continued at low altitude after the lights are turned off.

- When conducting practice night touchdown autorotations, the landing light or searchlight is turned on prior to entry into the maneuver and left on until

termination of the maneuver or the execution of a go-round.

CAUTION: *The landing light or searchlight may reduce visibility under certain atmospheric conditions. When these conditions exist, the landing light/searchlight should not be turned on until on final at approximately 200 feet.*

- The landing light or searchlight may be used to identify the helicopter position when entering the traffic pattern. Also, it may be used as a signal to alert the tower controller of radio failure.

AUXILIARY POWER UNIT

Operation of the aircraft lights during the preflight drains electrical power from the battery, reducing the available voltage. To insure that sufficient voltage is available to start the engine, an auxiliary power unit is recommended for starting the helicopter.

INFLIGHT PROCEDURES

The Aircrew Training Manual for each category of aircraft prescribes the flight technique for each task to be performed by the aircrew. Although the flight techniques for performing each task at night are the same as during the day, there are additional techniques for night flight which aid the aviator in performing the task at night. A knowledge of both the night techniques and the normal day flight techniques will enable you to perform any task at night for the category of aircraft being flown. Specific procedures that are peculiar to night flight are:

□ *Hover Operations.* Difficulty is experienced when hovering at night because visual ground references are not available. As a result, control inputs are made which cause the helicopter to move horizontally and vertically without realizing movement of the helicopter. The type of terrain over which the helicopter is hovered affects your ability to judge movement. Asphalt/concrete, grass, and water are types of surfaces you may be required to hover over.

● *Asphalt/concrete.* When hovering over an *asphalt/concrete* runway, it is difficult to estimate the hover height because there are no terrain features on the ground which aid in height estimation. Horizontal movement can be detected by observing the markings; e.g., runway centerlines, taxi lines, Maltese cross, and the lateral boundaries of the hard surface area. Movement is easier to judge when the contrast exists between the hard surface and grass areas along the lateral boundaries.

● *Grass.* When hovering over an open, *grass-covered* area, difficulty is experienced in maintaining altitude and a constant position over the ground. There are no ground references that can be used to estimate vertical or horizontal movement. This condition is further intensified when tall grass is encountered. The wavy motion of the grass gives an illusion of hovering over water. A normal tendency when hovering over tall grass is to hover at a higher altitude than what is judged and to inadvertently move laterally with the waves of the grass.

● *Water.* Water is the most difficult of all surfaces from which to judge movement from a hover. If possible, the

helicopter should be hovered near objects—tree stumps, buoys, shorelines—or a reference marker should be thrown into the water; e.g., life preserver, water flare. There is a tendency to move laterally with the waves. Accurate estimation of height is difficult, if not impossible, without a radar altimeter.

The illumination provided by the helicopter position lights aids in both height perception and detection of lateral movement. When operating in the *BRIGHT STEADY* mode, illumination from the lights can be detected at approximately 25 feet above the ground. Effective use of the lights to detect movement of the helicopter can be accomplished at 15 feet. Illumination from the position lights when operating in the *DIM STEADY* mode can be detected at approximately 10 feet. At 5 feet, sufficient light is available to detect movement of the helicopter. Both conditions vary according to the ambient light level and atmospheric conditions. The best effect is achieved from the position light during low light levels and low relative humidity.

When hovering with the aid of position lights, a common error is to stare at a single reference on the ground. This tends to induce autokinesis or disorientation. Reference points should be selected to the front and to the side of the helicopter. These references should be selected at varying distances from the helicopter. Continuous scanning is required to insure that all available references are used to detect movement of the helicopter.

On some helicopters, the shadow formed by the skid from the illumination of the position lights provides a good indicator for

identifying the altitude of the hover. As the helicopter ascends, the size of the shadow will become larger; and as it descends, the shadow will become smaller. Upon establishing a 3-foot hover, you should form a mental image of the size of the shadow for future reference. The intensity of the light on the ground and the distance the light is reflected from the helicopter are other techniques for gaging hover height using the position lights as an aid.

When hovering with the position lights on dim, a normal tendency is to hover too fast. This situation is difficult to overcome where ground references are not available. Continuous reference must be made to the side of the helicopter to observe for cues that will give an indication of forward speed. If hovering on a runway or taxiway, use the lights to the side of the aircraft to estimate forward speed.

CAUTION: Avoid fixation on runway center-line or taxi line during takeoff. This may cause spatial disorientation.

When hovering with the landing light or searchlight on, ground references are visible which enable you to detect movement of the helicopter over the ground and to estimate the height of the hover. The primary difference from a daylight hover is that references will be limited to the arc of illumination created by the light.

The positioning of the landing light/searchlight will significantly affect your night vision. When the beam of light is viewed directly, as much as 30 minutes may be required to night-adapt after the light is extinguished. To avoid this

condition, you should position the light so that you view only reflected illumination. For helicopters that are equipped with an adjustable landing light, extend the landing light to a position approximately 45° below the stowed position. This will cause the beam of light to strike the ground aft of the nose of the helicopter at a 3-foot hover, resulting in only reflected light to the front of the aircraft. If equipped with an adjustable searchlight, the beam can be directed approximately 30° to the left and slightly forward of the helicopter. Because the light beam is obscured by the instrument panel in side-by-side configured helicopters, only reflected light is viewed by the pilot.

As you become more proficient in hovering the helicopter at night, less reliance should be placed upon the use of the landing light/searchlight. The use of these lights degrade night vision and should be avoided when possible.

☐ *Takeoff.* Night takeoff procedures differ from daylight takeoff in that sufficient power must be applied to assure that an immediate climb is established as the helicopter begins to accelerate forward. The takeoff can be executed from a hover or the ground. Before takeoff, you should conduct a visual reconnaissance to determine if any obstacles are located within the takeoff path. The night takeoff should be an altitude-over-airspeed type takeoff until passing through an altitude which will assure obstacle clearance (fig 6-21). Because difficulty is experienced at night in determining if a climb has been established, you must cross-check the vertical speed indicator (VSI) to insure a positive climb has been established. Upon ascending to an altitude clear of obstacles, the

helicopter should be accelerated to the normal climb airspeed and the rate of climb. The ascent is continued until arriving at the desired altitude; at which time, the leveloff is accomplished.

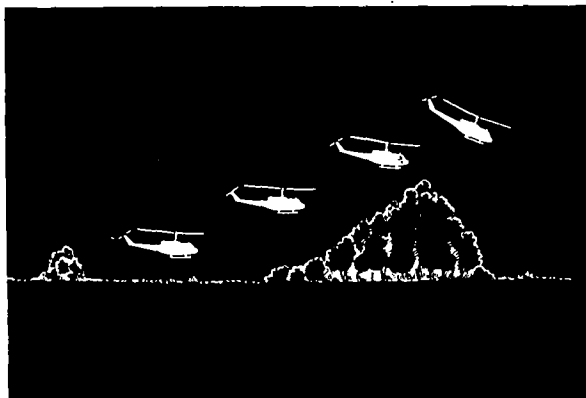


FIGURE 6-21. NIGHT TAKEOFF.

Takeoffs which are made with the landing light/searchlight on aid in detection of obstacles during the ascent. As the helicopter ascends, the illuminated area increases and the light intensity decreases. For helicopters equipped with an adjustable landing light/searchlight, adjust it far enough in front of the helicopter to assure that obstacles along the flightpath will be illuminated. As the helicopter ascends above the obstacles, the light should be turned off. Upon extinguishing the landing light/searchlight, you should be prepared to experience a sudden reduction of vision outside the helicopter. To assure positive control of the helicopter during the transition period, you should rely more on your flight instruments. As your night vision improves, outside references will be used to determine the helicopter's altitude.

Because of the lack of visual references during takeoff and throughout the ascent, difficulty will be experienced in maintaining desired ground track without referenc-

ing the aircraft heading indicator. Knowledge of wind velocity and direction will assist in establishing a crab angle which will result in the desired ground track. Where ground lights exist, select two distant lights to guide on. During the ascent, alinement of the lights should be maintained to assure the desired ground track.

☐ *Flight at altitude.* Upon ascending to the desired flight altitude, you should allow adequate time to adjust to the conditions of flight. This includes readjustment of the instrument lights, familiarization with the cockpit in the dark, and orientation of outside references. During this adjustment period, your night vision will continue to improve until total dark-adaptation is achieved. Landings without the aid of lights should not be attempted until dark-adaptation is completed.

To see effectively at the flight altitude, you must learn the techniques for viewing objects and terrain features at night. A thorough knowledge of principles of night vision (section I) is required in order to see other aircraft and to identify terrain features.

☐ *Landing.* Night landing will be executed to either a fixed landing site or a tactical landing site using the following flight techniques.

○ Prior to reaching the entry point on an approach, the touchdown point should be selected. When landing to a lighted helipad, this option is not available; however, if landing to a lighted runway or taxiway, a specific grouping of lights should be selected.

- A night approach should be slightly steeper and slower than an approach made during the day. If obstacles are not a factor, the angle of approach should be on the high side of the normal approach.

- Misjudgments of the helicopter's airspeed and altitude may occur which result in too fast an airspeed when terminating the approach. To avoid a tail low attitude close to the ground, airspeed should be dissipated at approximately 100 feet so that a loss of effective translational lift begins to take place at this altitude.

- During the approach, you may inadvertently reduce airspeed at too high an altitude without realizing it, thus creating an unsafe flight condition. To avoid this situation, cross-check the airspeed indicator during the initial part of the approach to insure the proper airspeed is maintained. Abrupt recovery from slow airspeeds may result in rapid loss of altitude when forward cyclic is applied. Coordinated control movement of both cyclic and collective is required to fly the helicopter along the desired approach path.

- The approach can be made to the ground or terminated at a hover. Approaches to the ground require the greatest degree of proficiency. Because the condition of the landing surface is difficult to ascertain at night, approaches to tactical landing zones are normally planned to terminate at a hover. If it is determined during the approach that the landing area is suitable for touchdown, the approach may be continued to the ground. A normal tendency when executing an approach to the ground is to stop forward motion before contacting the ground. Forward cyclic is required after passing through effective

translational lift to assure that the helicopter continues in forward motion. As the helicopter nears the ground, difficulty is experienced in estimating when contact will occur. A tendency is to "milk" the helicopter down. This technique requires more time to get the helicopter on the ground and usually results in overcontrol of the helicopter. This may cause the landing gear on one side of the helicopter to contact the ground followed by a ricocheting action of both landing gears. To avoid this situation, a gradual but continuous reduction in collective pitch should be made when terminating the approach.

- Approaches made using the landing light/searchlight are similar to daylight approaches. Height perception and rate of closure are more easily determined. Effective illumination will normally occur at approximately 200 feet above the ground. The landing light/searchlight should not be used during conditions when restrictions to visibility exist (e.g., fog, haze) because light is reflected back into the cockpit which may induce a safety hazard.

- The tactical lighting system does not provide as many visual cues as the lighting system for a fixed landing site. Also, approaches to a tactical landing zone are normally made without the aid of the searchlight/landing light. The lighting for a tactical landing zone may consist of hand-held flashlights or beanbag lights arranged on the ground. Regardless of which type of lighting device is used, a minimum of two lights should be used to identify the touchdown point. Because of the physical limitations of the eyes, an illusion occurs when viewing a single light that causes an apparent motion of the light. Two hand-held lights may not be

separated far enough to be interpreted as two lights when viewed on approach. Minimum separation of 15 feet between lights should be used. When more than two lights are used to mark the landing zone, spacing between lights can be reduced.

- A tactical lighting configuration used for landing to a tactical landing zone is the inverted "Y" (fig 6-22). It is best used for an approach initiated from terrain flight altitudes. The flight procedures and techniques for executing an approach to a tactical "Y" are—

- Prior to reaching the entry point for the approach, the lights in the stem will appear to merge as a single light (A, fig 6-22). This sight picture will also occur when the helicopter is on approach and below the desired angle of descent. When maintaining the normal approach angle, the "Y" appears as at B, figure 6-22. If the distance between the lights appears to increase, the approach is steepening and the helicopter is above the desired angle of descent (C, fig 6-22). The light would appear as in D, figure 6-22, when viewed from directly overhead.

- Alinement of the helicopter with the desired direction of landing is determined by observing relative position of the front two lights in relation to the stem. If the spacing between the front two lights and the stem is shifted to the left of the stem, you are too far to the right of course and should correct to the left (E, fig 6-22). If the spacing between the front two lights and the stem is shifted to the right of the stem, you are too far to the left of course and should correct to the right (F, fig 6-22). The desired touchdown point is midway

between the front two lights with the fuselage of the aircraft alined with the stem lights.

CAUTION: During the last 25 feet of the approach to a tactical lighting system you should divert your field of view away from the lights and concentrate on acquiring ground references. If you continue to concentrate your attention on the lights, you may fly the aircraft into the ground or develop spatial disorientation.

- Another tactical landing light configuration used when landing to an unimproved landing zone is the "T." It is

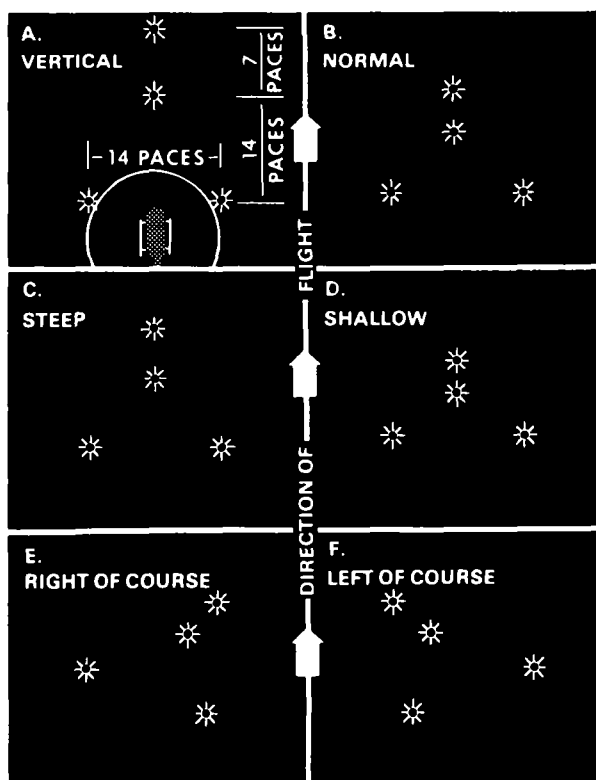


FIGURE 6-22. APPROACH TO LIGHTED LANDING ZONE

best used for approaches initiated from an altitude above 500 feet above ground level (AGL). The flight procedures and techniques for executing an approach to a tactical "T" are—

- The apparent distance between the lights in the stem of the "T" can be used as a reference for maintaining a constant approach angle. A change in the spacing of the lights will occur as the approach angle changes. Prior to reaching the entry point for the approach, the lights forming the stem of the "T" will appear to merge as a single light (A, fig 6-23). This sight picture may also indicate the helicopter is below the desired angle of descent. Upon intercepting the normal approach angle,

the stem of the "T" appears approximately as at B, figure 6-23. If the distance between the lights appears to increase, the approach is steepening and the aircraft is above the desired angle of descent (C, fig 6-23). The lights would appear as in D, figure 6-23, when viewed from directly overhead.

- Alinement of the helicopter with the desired direction of landing can be determined by observing the stem of the "T." If the stem points to the left of your position (F, fig 6-23), you are too far to the right of course and should correct to the left. If the stem points to the right of your position (fig 6-23), you are too far to the left of course and should correct to the right. The approach should be terminated in the upper left portion of the "T."

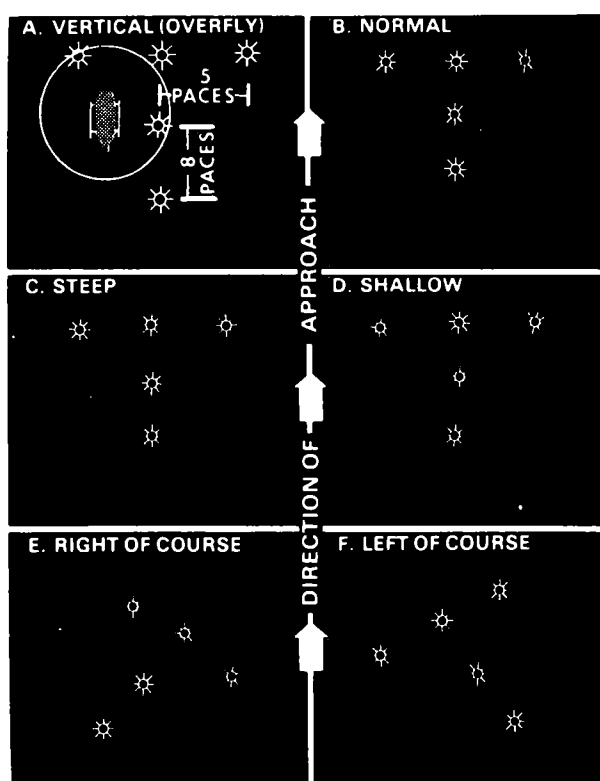


FIGURE 6-23. APPROACH TO LIGHTED T.

LANDING TO A GLIDESLOPE INDICATOR

The glideslope indicator is mounted on a universal joint which permits adjustment from zero to 15° above the horizontal. When flight is conducted in the center of any one of the three beams, a brilliant shade of the light is seen (fig 6-24). The green beam represents the desired angle of descent and assures your obstacle clearance if you stay within the beam. Also, obstacle clearance is assured by flying on the amber beam; however, the approach will be steeper than desired. Flight within the red beam indicates that the helicopter is too low and may be in danger. If the helicopter is allowed to drift to the extreme edge of the approach beams, the light intensity is reduced so much that all beams appear amber in color. You may think the helicopter is high and reduce collective pitch to lose altitude. If the error is not

corrected, the helicopter may hit an obstacle along the approach path.

CAUTION: When within 25 feet of the ground, you should direct your field of view away from the glideslope indicator and concentrate on acquiring ground references. If you continue to concentrate your attention on the glideslope, you may fly the helicopter into the ground or develop spatial disorientation.

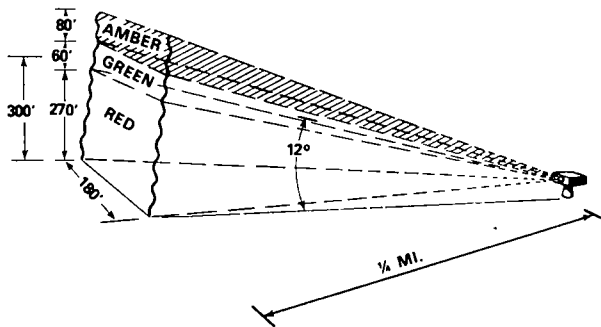


FIGURE 6-24. APPROACH LIGHT COLORS AND EFFECTIVE DISTANCES.

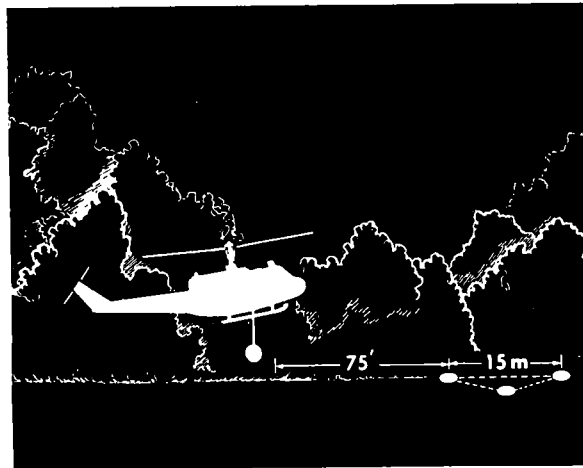


FIGURE 6-25. GROUND LIGHTING, SLING LOAD OPERATIONS.

EXTERNAL LOAD OPERATIONS

External load operations can be extremely difficult during hours of darkness. To successfully accomplish this maneuver, a triangular set of lights with a spacing of 15 feet should be positioned approximately 75 feet in front of the hookup area for use as a reference marker (fig 6-25). This lighting configuration aids the flightcrew during hookup, takeoff, and landing. Upon takeoff, climb vertically until the load is clear of the ground. As the helicopter begins forward movement, sufficient power must be applied to maintain a climb which will allow the sling load to clear obstacles along the takeoff path (fig 6-26). The shorter the sling, the less altitude required to clear



FIGURE 6-26. NIGHT SLING LOAD TAKEOFF.

EMERGENCY PROCEDURES

Emergency procedures for day flight and night flight are the same; however, the time required to respond to an emergency condition will normally be longer at night. This is due to the increase in psychological stresses and reduced vision within the cockpit at night. To minimize time delays in executing the required emergency procedures at night, you must know the location of all the controls and switches within the cockpit and the emergency procedures. Specific emergencies and recommended procedures that may be applied are as follows:

□ *Radio Failure.* If the primary radio fails, the secondary radio should be checked to determine if communication can be established with the controlling agencies. If communication cannot be achieved while in the traffic pattern at a field training site, a go-around should be executed, followed by a normal departure from the traffic pattern and return to the base field. Enter the traffic pattern and flash your landing light. If the tower operator fails to give a green light on final, fly the complete circuit. After completing a circuit, turn downwind and check the tower for a green light on base leg and final approach. Maintain a continuous watch for other aircraft in the traffic pattern and be prepared to initiate action required to avoid a hazardous condition.

If radio failure occurs during a training formation flight, you should use the visual signals to advise the flight leader of your emergency. Formation flight should be discontinued for the helicopter experiencing radio communications failure.

□ *Electrical Failure.* In the event of a total or partial electrical failure, non-essential systems requiring power should be turned off and a landing should be performed at the nearest facility that affords a safe landing. If the battery is operational, attempt to contact the tower when entering the traffic pattern. If contact cannot be made, fly a normal pattern entry. Remember, your aircraft will be difficult for other aircrews to see. You must take evasive action to avoid other aircraft in the pattern. When on final, you must decide if the approach can be continued without creating an unsafe condition for other aircraft. During the approach, watch the tower for light signals. If a green light signal is received, the controller will insure landing separation between aircraft in the traffic pattern and you are cleared to land.

AIRPORT TRAFFIC CONTROL LIGHT SIGNALS

When two-way radio communications with the control tower cannot be established, observe the tower for light signals which will identify the required action by the pilot. Acknowledgment of the tower light signal at night is accomplished by flashing the helicopter's lights (landing light or searchlight). Airport traffic control tower signals are identified in table 6-7.

VISUAL NIGHT SIGNALS

Air-to-air visual signals may be used by the aircrews at night when the radio is inoperative or when maintaining radio silence. They may be used to signal an escort helicopter or the control tower of the distress. A unit SOP should be developed which identifies the visual night signal to be used during emergency situations. The

following visual night signals are a guide for development of a more complete unit SOP.

☐ *Helicopter emergency*—must land as soon as possible. If the nature of the emergency allows, the distressed pilot signals the escort helicopter by describing a circle on the side window with a flashlight; then maneuvers to the escort helicopter wing position. The escort pilot leads to the nearest suitable field, declares an emergency with the controlling agency, and then flies a straight-in approach with the distressed helicopter on his wing. The distressed helicopter lands and the escort executes a go-around. While en route, the escort helicopter plans to fly the normal cruise airspeed of the distressed helicopter. If this airspeed is too fast, the pilot of the distressed helicopter signals by blinking his flashlight once for each 10-knot decrease desired.

☐ *Aircraft having minor difficulty*. The distressed aircrew signals another aircrew in the formation by a series of flashes from a flashlight, then maneuvers to the wing position of the escort helicopter. The airspeed and flight procedures are the same as specified in the above except that the escort helicopter leads to the intended landing field but does not declare an emergency in doing so.

☐ *Signal acknowledgment*. An aircrew-member of the escort helicopter points a steady light from the flashlight at the signaling helicopter. If the message is not understood, respond by blinking the flashlight.

TABLE 6-7. AIRPORT TRAFFIC CONTROL TOWER SIGNALS.

Color and type of signal	On the ground	In flight
Steady Green	Cleared for takeoff	Cleared to land
Flashing Green	Cleared to taxi	Return for landing (to be followed by steady green at proper time)
Steady Red	Stop	Give way to other aircraft and continue circling
Flashing Red	Taxi clear of landing area (runway) in use	Airport unsafe; do not land
Flashing White	Return to starting point on airport	
Alternating Red & Green	General Warning Signal—Exercise Extreme Caution	
Red Pyrotechnic (Red Flare)		Notwithstanding any previous instructions, do not land for the time being

AIRFIELD AND HELIPORT LIGHTING

To insure a safe operating environment, an understanding of the standard colors for airfield and heliport lighting is required.

The aviation colors for Army airfield marker lights will be as follows:

- ☐ Lateral limits of runways (airfield)—white (clear).
- ☐ Lateral limits of runway (heliport)—alternating white (clear) and blue.
- ☐ Threshold lights defining ends of usable landing area—green.
- ☐ Taxiway lights—blue.
- ☐ Entrance or exit taxi—guidance lights at intersections (throat) of taxiways with runways or aprons—blue.
- ☐ Approach lights for instrument approach facilities and instrument flight rules (IFR) procedures if directed—white and red.
- ☐ Obstruction lights—red.
- ☐ Wind direction indicator—white (clear).
- ☐ Obstruction—red.

The aviation colors for Army airfield and heliport beacon lights are as follows:

- ☐ Attended land airport—white (double or split beam—green).

☐ Attended land heliport—white (flashing clear light, 50 to 80 flashes per minute).

☐ Hazard beacon—red.

GROUND SAFETY

When walking on the flight line at night, you should illuminate your pathway. This procedure identifies obstacles on the ground along your pathway and your position to aircrews hovering aircraft in the near vicinity.

During the preflight at night, you should pay particular attention to structural components of the helicopter which are difficult to see at night. Before moving forward to check another component of the helicopter, the flashlight should be shone forward to insure that no obstructions lie in your path. An example of a structural component on the UH-1 helicopter which has caused serious injury to aircrew-member is the synchronized elevator. This component is at about the same level as the head and can cause serious injury if caution is not exercised when preflighting this area of the helicopter.

When climbing upon the helicopter at night, extreme care must be exercised to insure that surfaces are clear of oil and hydraulic fluid. These conditions are common in and around the transmission and rotor head. Extreme care must be exercised to insure you do not lose your balance and fall during preflight of the rotor assembly.

AIR SAFETY

You must be aware of the limitations of night vision and must not overestimate your ability to conduct night flight. After initial qualification, continuous training is required to remain proficient. If night flight has not been conducted for a lengthy period of time, simple maneuvers should be performed before attempting more advanced maneuvers.

Because flight attitude references are limited at night, vertigo is easily induced. You must be aware of this condition and rely on your instruments to assure a normal flight attitude. When hovering without the aid of the landing light/searchlight, vertigo is a common occurrence. To avoid this condition, the landing light should be turned on whenever an unsafe condition exists.

To assure immediate and positive response to an inflight emergency, each crewmember should become familiar with the location of controls and switches within the cockpit.

Continuous observation outside the helicopter is required to insure avoidance of obstructions and other helicopters. These conditions become increasingly hazardous when conducting flight in and around field training sites.

SECTION V

TERRAIN FLIGHT

THREAT AVOIDANCE

Detection avoidance is as important at night as during the day when operating in a high threat environment. Visual acquisition by the enemy is more difficult; however, his electronic detection capability is not degraded. To avoid detection by threat weapons, you must move about the battlefield at night at terrain flight altitudes. Your ability to perform terrain flight at night will depend upon the ambient light level, flight proficiency, familiarity with the terrain, and availability of night vision devices.

PREREQUISITES

To achieve the greatest benefits and to provide a safe operating environment, the following prerequisites are required before conducting night terrain flight training:

☐ A thorough eye examination should be conducted to insure that there are no restrictions to night vision. An aviator who has adequate day vision may have poor night vision or vice versa. An eye examination will detect a visual deficiency which will adversely affect one's night vision.

☐ The student must have completed a day terrain flying course of instruction. The flight techniques of night terrain flight very closely parallel day terrain flight and serve as a basis for expanding the student's knowledge in terrain flight. A student who is given night terrain flight training and has not qualified in day terrain flight will require additional flight training to achieve the same degree of proficiency as a student who has qualified in day terrain flight. In addition, students without previous training in terrain flight pose a high safety risk for conducting night terrain flight.

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□ Night terrain flight academic subjects should be taught prior to the student receiving night flight training. The accomplishment of this training provides an awareness of the limitations of night terrain flight for the student, thus insuring a safer operating environment.

□ Training for night terrain flight should be conducted in the type helicopter the aviator will pilot during a tactical mission. When this cannot be accomplished, the aviator must undergo night familiarization training in the helicopter that is normally flown by the aviator.

□ The minimum aircrew requirements consist of two qualified aviators or one crewmember may be an observer who has been trained in night terrain flight. Because of the limitations inherent with night terrain flight, one aviator cannot be expected to navigate and fly the helicopter. Passengers should also be used to assist in terrain recognition.

□ To increase the aviator's night vision capability and insure a greater degree of safety it is recommended that the helicopter should be configured as follows:

- Crashworthy fuel system.
- Armor seats.
- Glass windscreens.
- Interior and exterior lights should be configured as described in the appropriate TC series "preparation for night flight."

COMMAND CONSIDERATIONS

When aircrews are scheduled for night terrain flight, consideration should be given to limiting their workload to night flights only. To employ aviators in both roles will degrade their capability to effectively operate in a night environment. Because night terrain flight is more fatiguing, commanders must insure that aircrewmembers are afforded optimum conditions for rest.

Maintenance requirements to support day and night flight will be greater than what is normally experienced. To allow for sufficient time for maintenance, commanders should decrease day operations when night flight is scheduled. Maintenance personnel may be required to be divided into two shifts to support concurrent day and night operations.

Commanders should be alerted to detect and recognize signs of fatigue, overconfidence, or carelessness displayed by aircrews engaged in night terrain flight. A carefully planned and vigorously executed safety and night flight awareness program is essential for accident-free operations. Commanders are responsible to insure that leaders at the lowest level emphasize and enforce the spirit as well as the standards of the safety program.

Commanders must insure that the proper facilities are made available for night training. A list of special equipment and facility requirements is identified in section IV. Failure to provide the proper training environment will degrade the aviator's

ability to perform night flight and will create an unsafe environment for conducting night terrain flight.

LIMITATIONS

To successfully operate at terrain flight altitudes at night, you must be aware of the hazards and limitations and learn to cope with each. The most serious hazards and limitations of night terrain flight are—

□ *Psychological and Physiological Stress.* During day terrain flight, great distances can be seen and the aircraft can be safely maneuvered to avoid obstructions along the flightpath. At night, vision outside the aircraft is very limited; and during periods of low-light levels, it is difficult to see obstructions that lie along the flightpath. Awareness of this limitation causes fear to exist within you. As a result, fatigue develops, judgment is impaired, reaction time is slower, and flight proficiency is degraded. As you become more experienced in night terrain flight, more confidence is developed in your ability to conduct night flight. Continuous flight training and rigid application of the factors for personal preparation (section IV) are necessary to cope with limitations associated with psychological and physiological stresses.

□ *Hemispherical Illumination.* Because the phase angle of the moon changes daily, varying levels of light will be experienced each day of the moon's cycle. Also, the moon's altitude changes each hour of the night causing a change in available light.

Detailed planning is required to determine when the optimum day and hour exist for conducting night terrain flight. The light level will dictate the mode of terrain flight that can be flown.

□ *Meteorology.* Cloud coverages which normally would not restrict day terrain flight may prevent night terrain flight. At night clouds obscure the illumination from the moon and other hemispherical bodies. The density of clouds and the amount of sky coverage will determine the available light that will be received on the ground. Restriction to visibility—light drizzle, fog, haze—also limits the available light. To conduct night terrain flight, sufficient light must be available to see objects and terrain features which lie along the flight route. When visual acuity is reduced to the point that terrain interpretation is ineffective, it is unsafe to continue the mission. Climbing to a higher altitude will not improve your visual acuity and may subject the aircraft to detection by threat weapons.

□ *Navigation.* Navigation at terrain flight altitudes is difficult because the helicopter is flown at such low altitudes and the distance that an object can be seen is significantly reduced. Although the helicopter is flown at a slower airspeed, the apparent groundspeed appears to be faster when flying to terrain flight altitudes. As a result, viewing time is reduced which further restricts ease of navigation. Because of these limitations, accuracy of navigation is difficult and disorientation is likely. Positive identification of manmade or natural features is required to insure accurate navigation. Detailed planning and teamwork are the key to insure the success of the mission.

☐ *Tactical Landing Lights.* The tactical landing light system provides visual cues for landing in a tactical landing site. The inverted "Y" is the recommended tactical lighting system when the approach is made for terrain flight altitudes.

CAUTION: Never use only one light in the landing zone to identify the touchdown point. If two lights are used, a minimum of 5 meters separation should be used to correct for the physical limitations of the eyes.

☐ *Aircraft Maintenance.* Maintenance should be given highest priority. Personnel who maintain the aircraft must perform quality maintenance. To insure that sufficient time and adequate light are available for conducting maintenance, it is recommended that those helicopters that will be flown at night not be flown during the day or stood down in the afternoon. When possible, preflight inspection by the aircrew should be performed prior to darkness.

The windscreens must be thoroughly cleaned prior to each flight. Aircraft with scratches on the windscreens that distort vision should not be flown.

Design of the present aircraft lighting system degrades the aircrew's night vision. To minimize the adverse effect of the aircraft lights on night vision, the aircraft should be prepared for night flight. The aircrew should use the aircraft lights as recommended in the appropriate TC in the "preparation for night flight" series.

☐ *Night Vision.* The degree of night-adaptation of the eyes will determine how well you can see at night. Proper procedures must be followed to become night-adapted. If you are exposed to a light source at any time during or after the eyes become night-adapted, a loss of night vision will be experienced. The facility commander should enforce light discipline and provide the special equipment discussed in section IV. Procedures for using aircraft lights and preparing aircraft for night flight outlined in section IV and the applicable TC in the "preparation for night flight" series should be followed.

Exposure to light sources is not only limited to the flight facility. In combat the enemy may use high intensity lights to illuminate the aircraft. Other sources of light on the battlefield are fires, weapon flashes, lightning, and city lights. Every effort must be made to avoid direct viewing of these light sources. Normally, exposure to a light source does not affect both crewmembers to the same degree. The one who is affected the least should pilot the aircraft.

☐ *Maps.* Any light sources in the cockpit used to read the map degrades the pilot's vision outside the aircraft. In addition to this limitation, the tactical map is unsatisfactory for night use. The following are problems that are encountered when using the tactical map at night.

- Contour lines cannot be detected when viewed with a red light.

- The surface of the map reflects light on the windscreen.

- Objects that are easily recognized at night are not shown on the map.

- Too much irrelevant detail is shown on maps. Political boundaries, names of roads, underground features, ruins, and other features not visible at night clutter the map.

- Significant terrain features on the ground are not recognizable on the map because the contour lines are not visible or need shading or highlighting to identify prominent terrain features.

□ *Manmade Obstructions.* Detection of wires and other manmade obstructions is difficult at night. The best means of avoiding wire strikes at night is to fly at a reduced airspeed. By slowing down, more time is available to detect wires and to take evasive action. Identification of wires is accomplished by association with manmade features. Wires will first be detected by recognizing the poles to which the wires are attached. Normally, these poles can be found beside highways. If a dwelling is observed in an open area, wires can be anticipated in the field near the building. Because trees are normally higher than wires, the possibility of striking a wire is less likely to occur when flight is conducted over a forested area. Transmission lines suspended on steel structures pose the highest wire obstacles. These structures may be as high as 110 feet. Prior knowledge of the existence of a manmade obstruction is essential. Information relating to these obstructions should be plotted on a hazard map and made available to the aircrews when planning a night terrain flight.

During night terrain flight, helicopters are particularly vulnerable to blade strikes

when operating in confined areas. Extreme care must be taken when performing masking and unmasking maneuvers and when hovering within a confined area. The area where these maneuvers are performed at night should be larger than that required during the day. Crewmembers should assist by advising the pilot of the helicopter's position in relation to obstacles.

In addition to wires and trees, birds are a hazard to night terrain flight. Normally, they have a nesting area which once located can be avoided. Upon encountering a flock of birds, maintain heading. Any abrupt change in heading may cause inadvertent contact with terrain obstacles or it may induce vertigo because of the sudden change in attitude. Since birds tend to disperse laterally with little ascent, a straight ahead climb will normally clear the helicopter of the birds.

MISSION PLANNING

The factors used by an aviator for planning a mission requiring the aircraft be flown at terrain flight altitude are the same as for a day mission. For detailed information on mission planning, refer to Chapter 5, "Terrain Flight."

NAVIGATION

Due to the continuous heading and airspeed changes, dead-reckoning navigation is not normally used; however, where recognizable terrain features are not available, it may be used for short distances.

Estimations—by the pilot's senses—of distances and times flown are misleading and normally result in disorientation. When using dead reckoning navigation, estimates must be computed and a constant airspeed and heading maintained.

The primary means of navigation is pilotage. Each crewmember should memorize the layout of the flight route and prominent checkpoints. As the helicopter is flown along the route, a continuous comparison should be made between what is seen on the ground and what is represented on the map. It is essential that the copilot know the location of the helicopter at all times. Deviation from the preselected course for better cover and concealment and faster airspeed should be considered where orientation can be maintained with a prominent feature located along or near the course. A more detailed discussion of terrain flight navigational techniques is provided in Chapter 5, "Terrain Flight."

DISORIENTATION PROCEDURES

During conditions of low ambient light, visual range is reduced. This condition restricts the pilot's ability to positively identify a recognizable terrain feature close in to the helicopter by reference to a prominent terrain feature at a greater distance. At night there is a tendency to misidentify terrain features that resemble those on the map. This error may not be detected until the helicopter has flown off course a significant distance. When it becomes apparent that disorientation has occurred, you should attempt to identify your position with a ground reference. If

you cannot, return to the last known position. Further flight in anticipation that a recognizable terrain feature will be identified seldom results in reorientation; therefore, you should not attempt it.

CREWMEMBER RESPONSIBILITIES

The individual crewmember's responsibility for night terrain flight is the same as for day flight. For detailed information relating to crewmember responsibilities refer to chapter 5, "Terrain Flight."

FLIGHT TECHNIQUES FOR TERRAIN FLIGHT

□ *Takeoff.* Night terrain flight takeoffs are performed without the aid of the searchlight/landing light. Before the takeoff, you should conduct a visual reconnaissance of the departure path. Obstacles can be recognized by silhouetting them against the skyline. Recognition of obstacles will be difficult during the ascent because the viewing angle changes, causing the obstacles to blend into the background. Sufficient power should be applied upon takeoff to insure that a positive rate of climb is achieved and ground roll is avoided. Just prior to the helicopter's reaching the desired terrain flight altitude, power is reduced and the attitude is adjusted to achieve the desired airspeed. When wind and obstacles are not a consideration, takeoff heading should be planned in the direction of the first leg of the route to be flown. If this cannot be

accomplished, it may be necessary to reverse the course and pass over the landing zone in the direction of the first leg of the route. This procedure insures positive orientation.

□ *Inflight.* During the flight, the pilot's and copilot's windows should be down on helicopters which have this configuration. Unobstructed viewing improves the aircrew's visual acuity. To further enhance the aircrews night vision, it is recommended that the doors on helicopters which allow this configuration be removed. Cargo doors that can be locked in the open position will enable aircrewmembers in the cargo section to view outside the helicopter with undistorted vision. It is recommended that helicopters with tinted windscreens not be flown at night.

□ *Hovering Without the Aid of Lights.* When hovering is performed without the aid of lights, difficulty will be experienced in detecting movement of the aircraft. During periods of mid and high ambient light, terrain or physical features can be identified. To judge movement, attempt to locate a distinguishable feature on the ground and establish a reference point on the aircraft with the ground cue. A change in the viewing perspective provides a cue for movement. If the aircraft is being maneuvered within an area, the process of identifying ground cues and reference points on the aircraft must be repeated upon passing each ground reference. When hovering without the aid of lights, movement should be performed very slowly.

The silhouette of trees and manmade structures as viewed against the skyline also provides a cue for determining hori-

zontal movement. By viewing the two references, lateral movement can be detected by a change in the viewing angle. Vertical movement is detected by observing the viewing angle against the skyline. If the silhouette becomes smaller, the helicopter is climbing; if it becomes larger or more distinguishable, the helicopter is descending. If at anytime while hovering, you feel an unsafe feeling exists, turn on the exterior lights to regain orientation.

As the hover height increases, greater difficulty is experienced in judging movement and height above the ground. Hovering near ground features such as a road; a cleared area where contrast between the tree line and opening is discernible; or near features that have vertical development above the visible horizon, provides a good cue for judging movement. When attempting to maintain a hover out-of-ground-effect, care must be taken not to climb and allow the reference to enter defilade below the visible horizon. If this condition should occur, descend very slowly until the reference becomes visible. Spatial disorientation is easily induced by changing your visual reference from the flight altitude to the ground. Crewmembers should assist the pilot by observing ground reference to determine movement.

The aircrew should become familiar with the configuration of the cockpit to the point that each can identify all essential items for flight without the aid of lights. This can be accomplished by requiring the aircrew to conduct blindfold cockpit checks. Standardization of locating items of equipment—radio panels, control switches, flashlight—within the cockpits of helicopters should be adopted and incorporated into unit SOPs.

When conducting night terrain flight, very little reference will be made to flight instruments by the pilot. Heading control will be difficult. When viewing through the side window, there is a tendency to bank the aircraft to the right which causes an undesirable heading change. When the copilot observes an undesirable change in the heading, he should advise the pilot and request that action be initiated to correct the condition. Recommended changes in heading by the copilot should be given using rally terms (e.g., turn left, stop turn).

Night terrain flight is normally conducted below cruise airspeed. To maintain this airspeed, the helicopter must be flown in a nose-high attitude. For some helicopters, this attitude restricts the forward vision of the pilot. Because the attitude is unusual, and there is no visual horizon, there is a tendency to lower the nose. As a result, the helicopter will accelerate. This higher airspeed increases the difficulty of navigation. To overcome this problem, establish an attitude which will result in the desired airspeed and identify references on the skyline or within the helicopter which will assist in maintaining this attitude.

The fuselage of a single-rotor aircraft will not streamline and overcome torque below 40 knots. As a result, antitorque control is required at slow airspeeds. As the airspeed decreases, a greater requirement for anti-torque pressure is required to align the helicopter in the direction of flight. Application of antitorque pressures takes power away from the engine and must be considered when conducting terrain flight. The condition that requires the greatest

amount of power to drive the tail rotor is hovering out-of-ground-effect (OGE) with a crosswind from the right. This condition becomes more severe at higher altitudes. When hovering in-ground-effect (IGE) at elevations above 5,000 feet, effective control may be lost.

Estimation of altitude above terrain features during the descent is misleading. When descending to a lower altitude, a gradual reduction in altitude should be planned. A series of descents and leveloffs should be performed until arriving at the desired altitude. This procedure enables you to adjust to the different altitudes gradually and precludes inadvertent descent into a terrain feature.

Rapid flight attitude changes to initiate descents, climbs, turns or airspeed should be avoided. Changes in the flight attitude degrade the aircrews viewing perspective outside the aircraft and may induce vertigo.

☐ *Landing.* Because your vision is reduced at night, the landing zone should be larger than those required during the day. Also, landing zones should be selected which are relatively clear of obstacles on approach and takeoff paths. When making an approach without the use of any ground aircraft lights over a forested area into an open field, contrast between the dark trees and the lighter color of the open area will aid in identifying obstacles along the boundary of the landing zone. The forward and lateral limits of the landing zone will appear darker when contrasted with the open area.

The time between entry point and touchdown for the night approach from

terrain flight altitude is much shorter than the normal approach discussed in section IV. Because line-of-sight with the landing zone cannot be established until relatively close in, airspeed should be reduced prior to intercepting the desired glidepath so that the approach can be performed without a rapid deceleration. The approach should be executed with a slower rate of closure which allows more time to judge height and minimizes forward motion in the event of premature ground contact.

During the approach, vision will be restricted when viewing the landing area through the windscreen. The landing area will appear blurred, resembling a haze layer below the tree line. This condition improves as the aircraft gets closer to the touchdown point. Throughout the approach the copilot provides information to the pilot concerning obstacle avoidance, altitude, airspeed, and the approach angle. Viewing through the side window will aid in estimating the height of the helicopter. If the approach is made to tactical lights, lateral movement can be detected by the relative position of the helicopter in relation to the lights. Night approaches to an unlighted area should be planned to terminate at a hover followed by a slow vertical descent until ground contact.

MULTI-HELICOPTER OPERATIONS

Because of reduced vision at night, formation flying cannot be safely conducted at terrain flight altitudes. When more than one helicopter participates in night terrain flight, the term "multiple" helicopter operation is used in lieu of

"formation." This term emphasizes the priority and precedence of independent action required by each aircrew to maneuver the helicopter to insure obstacle avoidance and accuracy of navigation.

□ *Inflight Procedures.* As the number of helicopters in a multi-helicopter operation increases, control becomes more difficult due to the distance which separates the lead and trail helicopters. Also, separation aids in detection by enemy ground forces because more time is required for the flight to pass over a position on the ground.

Multi-helicopter operations at terrain flight altitudes normally will be flown in a trail or staggered trail formation with approximately 10-second separations. This procedure allows the aircrew to concentrate more on detection of obstructions and navigation. Each aircrew in the flight is responsible for the accuracy of navigation and must be prepared to take the lead at any time and proceed to the destination. To insure the success of the mission, each helicopter aircrew in the flight must function as an integral element of the team. Assignment of responsibilities should be made prior to the mission. To insure minimum radio communications during the mission, a thorough premission briefing is required. Light signals and code words should be standardized to assist in reducing radio communications. These visual signals should also be used in the event of lost communication and radio jamming by the enemy.

The aircraft lighting configuration for multi-ship operations requires that the navigational lights be operated in the lowest intensity possible and partially

taped and the anticollision light turned off. The distance between aircraft is judged by observing the intensity of the navigational light. If the light intensity decreases, the distance is increasing. Conversely, if the light gets brighter, the distance is decreasing. Turns and airspeed changes by the forward helicopter are determined by the apparent elongation and shortening of the distance between the lights.

□ *Disorientation Procedure.* Prior to the mission, disorientation procedures will be established and executed upon the command of the flight leader. The first step is to recognize that the flight is disoriented. Normally, disorientation can be avoided if each aircrew is following the route of flight on the map. If at any time during the mission it is detected that the flight leader is off course, an aircrewmember should advise and assist the leader in reorientation. If a situation arises where the entire flight becomes disoriented, the flight leader should stop the flight and attempt to reorient its position. If this cannot be accomplished, the flight should reverse

course and backtrack until positive identification of a terrain feature can be made. The recommended procedure is for each helicopter to execute a 180-degree turn in position and follow in trail. The trail helicopter becomes lead and lead becomes trail. Upon reorientation, each helicopter in the flight will reverse course in position and the original flight leader will resume command of the flight.

□ *Helicopter IFR Breakup and Recovery Procedures.* Under normal circumstances, the entire multi-helicopter flight will not enter into instrument meteorological conditions if the proper spacing is maintained. However, unplanned entry into IMC cannot be ignored. Units should develop a helicopter IFR breakup and recovery procedure which is a part of the vertical helicopter IFR recovery procedure. During training, these procedures should be continually emphasized and practiced. A recommended procedure that can be used as a guide for developing an IMC separation procedure is contained in chapter 9 of this publication.

SECTION VI

NIGHT VISION GOGGLES, AN/PVS-5

EMPLOYMENT CONSIDERATIONS

Enemy forces recognize how important the ambient light level is to an aircrew conducting night terrain flight using unaided vision. As a tactic to reduce the effectiveness of Army aviation, the enemy will plan combat actions when the light level is low. During this condition, terrain flight cannot be performed without subjecting the aircrew to an unacceptable

degree of risks. To operate at terrain flight altitudes during low/mid light level, night vision devices must be used. Although devices are available which turn the battlefield into daylight, most of these devices emit a detectable source of energy. To avoid detection and still be able to see during conditions of low/mid light levels, passive devices must be used. The AN/PVS-5 night vision goggles (NVG) is a device currently available to aircrews.

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PSYCHOLOGICAL AND PHYSIOLOGICAL CONDITIONING

The normal response of most rated aviators to night vision goggle training is to let the new aviators develop this new skill. Strange as it may seem, these new aviators are anxious to undergo NVG training if their instructor pilot (IP) doesn't discourage them too much. Why is this true? Well, NVG training is something new; it's a challenge, and the experienced aviators have formed a negative opinion. This happens each time a new requirement arises. Several years ago nap-of-the-earth training was introduced. The first response was, "It's dangerous; the accident rate is going to increase significantly." In reality, the accident rate did not increase; and today, units perform NOE flight routinely.

Conditions exist at night where extreme caution must be exercised; however, it is possible to overcome the fears that confront you in NVG training. Initially, you will become very fatigued; a headache may develop; your neck muscles may become sore; anxiety will develop because you cannot see color; and perspiration may occur, causing a very uncomfortable feeling. To overcome the psychological and physiological barriers that confront aviators undergoing NVG training, the following considerations should be incorporated into the training program:

The initial flight with the goggles should be limited to one-half hour and conducted when a high light level exists. This procedure introduces the student to the goggles during ideal conditions and is short enough to avoid becoming fatigued. As training progresses, longer training periods can be planned and the ambient light level can be lower. This will increase the student's endurance and he will gain confidence in his ability to fly. As a result, anxiety and fear are no longer a problem. The headaches and sore neck that might have developed are not experienced.

☐ Consideration must also be given to the IP workload. Regardless of the student IP ratio, the maximum time flown by the IP during a training period should not exceed 3 hours. The training period should be broken down into two 1 1/2 hour flight periods. Between flights, the IP should be given the opportunity to remove the goggles and move about outside the aircraft.

☐ When undergoing night training, the student, IP, and support personnel operate

on an inverse schedule. To attain optimum efficiency, duty hours for aircrewmembers should not exceed 8 hours a day. To comply with this requirement, duties should be limited to flight training only. Additional duties, which require an aircrewmember to be present for duty during the day, should be avoided when possible.

☐ To insure the student is aware of conditions that may be encountered when flying with the night vision goggles, academic subjects relating to the system should be presented before conducting flight training.

EFFECT OF AMBIENT LIGHT ON NIGHT VISION GOGGLES

To fully realize the benefits that are gained from the NVGs, you should know how light affects your ability to see at night with the goggles. The basic considerations you must be aware of include—

☐ The NVGs do not magnify an image. An object or person that can be seen at a given distance during the day will probably be seen at night; however, the resolution will not be as good. Under the best conditions, visual acuity with the current NVG system is never better than 20/50. Things that are hard to see during the day—wires, camouflaged equipment—will be more difficult to detect with the goggles. How well you can see depends on the level of ambient light. During periods of high ambient light, resolution is improved and you can identify objects at greater distances.

☐ Light sources emitted by a vehicle or person—driving lights, flashlight,

cigarette—can be detected at great distances even though the light is undetectable with the unaided eye. The capability of the goggles to detect these light sources improves as the light level decreases. During periods of high ambient light, detection of light sources is more difficult; however, visual detection of an object or terrain feature is improved.

☐ Effective viewing through the goggles can be accomplished without allowing time for the eyes to adapt. The light intensity that is viewed through the goggles does not allow the eyes to fully adapt; however, the time required to night-adapt for unaided vision would be reduced approximately 50 percent to 80 percent after wearing the goggles.

☐ When viewing an area illuminated by an artificial light source—flare, landing light, built-up area—you will not be able to see anything outside the periphery of the area being illuminated. Your ability to see objects within the area being illuminated depends on the intensity of the light and the distance it is from your position. Direct viewing of the light source should be avoided. If exposed to a high intensity light source, normal viewing is regained by turning away from the light sources. No recovery period is required to allow the eyes to adapt as would be experienced if the unaided eye was exposed to a light source.

☐ Any light source within the cockpit that is detectable with the unaided eye will degrade your ability to see outside. Illumination from exterior lights degrades your vision outside the periphery of the area illuminated by the lights. The adverse effect of aircraft lighting on the goggles is

greater during conditions of low ambient light. As the light level increases, aircraft lighting has less effect on the goggles.

GENERAL DESCRIPTION

The AN/PVS-5 night vision goggles are a self-contained night vision device worn over the eyes. The system uses light amplification to provide night vision and is not detectable when operated in this mode. It does not provide any image magnification capability. An auxiliary infrared light source is incorporated into the system which provides illumination for viewing up to 2 meters. When operating in the infrared mode, detection by Threat forces is possible. A 2.7-volt battery is required to operate the system. Installation of the battery is performed by the user. This battery is recoverable but not rechargeable.

The goggles consists of a binocular unit consisting of two identical monocular assemblies (tubes) mounted in an adjustable frame. Each tube consists of an objective lens, an image intensifier assembly and an eyepiece. Operation of the system is controlled by a three-position switch (ON-OFF-IR). When the switch is moved to the ON position, the system is activated and viewing through the goggles is possible. The goggles should never be turned on in the daylight or in a lighted room. Exposure to sunlight or a high-intensity light source damages the tubes. If the goggles must be turned on during the day or in a classroom that is illuminated to test the system, the objective lens covers should be left on. A pinhole in the covers provide sufficient opening to conduct an operational test without damaging the tubes.

The binocular assembly housing is constructed of a plastic material and lined with a cushion which rests on the cheekbones. The entire unit is approximately 6.5 inches square, and weighs 28 ounces. It protrudes approximately 6.5 inches in front of the eyes.

☐ To improve visual acuity, the goggles must be focused for the range at which an object is being viewed. The focusing range is from 10 inches to infinity. Adjustments are made by rotating the tube cylinder. With the goggles positioned on the head clockwise, rotation of the tube moves the focus inward, whereas counterclockwise movement moves the focus toward infinity.

☐ The state of charge of the battery cannot be determined prior to near depletion of its electrical power. A blinking or dimming condition in both tubes indicates that the battery is weak and should be replaced. The normal battery life is approximately 12 hours at 70°F. Accurate records should be maintained so that the aviator knows how many hours the battery has been used. If in doubt as to how many hours the battery has been operated, replace it before conducting night flight with the goggles. Each aircrew should insure that the battery time for one set of goggles does not exceed 10 hours during the flight. If this policy is followed, a high probability exists that both aircrewmembers will never experience battery failure at the same time. Batteries that have exceeded the recommended shelf life should not be used. Experience has proven that the life of these batteries is significantly reduced.

☐ The NVGs have proven to be very reliable. Failures of the system are nor-

mally attributed to weak batteries or broken wires. Currently, there is no means for testing the condition of the tubes. Failures that have occurred have provided the user advance warning. The first indication is a significant differential in light intensity between the two tubes. Also, a blinking condition may occur in one of the tubes. When either condition is observed, the weak tube should be replaced.

☐ The goggles have a 40-degree field of vision. Due to this limitation, a loss of peripheral vision is experienced. Also, references within the cockpit used by the pilot to establish the flight altitude are not available. Greater reliance must be placed on the proper scan technique.

ADJUSTMENTS FOR NIGHT VISION GOGGLES

There are three adjustments that can be made to the goggles to correct for individual differences. They include—

☐ The distance between the tubes can be varied by releasing the interpupillary guide level clamp. This adjustment should be made so that the tubes are properly aligned with your eyes. Failure to accomplish this adjustment will increase fatigue of the eyes.

☐ The binocular assembly can be moved fore and aft and tilted up or down. This allows you to adjust the eyepieces to a position that is comfortable to the eyes. Adjustment is made by loosening the transverse frame clamp knob on each side of the goggles. Upon loosening each clamp knob, the entire binocular assembly will

move fore and aft and tilt up or down. After the proper adjustments have been made, the clamp knobs should be tightened.

□ Each tube is equipped with a diopter adjustment ring. This adjustment allows you to correct for vision deficiencies such as myopia and hyperopia. The range of the diopter is a +2 to -6. The diopter does not correct for astigmatism. Individuals with a 1.00 or greater diopter of astigmatism will experience blurred vision when viewing through the goggles. Due to the vision limitations that aviators with astigmatism of 1.25 or greater will experience, consideration should be given to limiting them to navigator duties. To determine your diopter setting, adjust the focus knob to infinity and view a light at a great distance. Adjust the diopter ring until the light is seen very distinctly. This procedure should be performed for each eye and for each set of goggles that is used.

FITTING FOR NIGHT VISION GOGGLES

Proper fitting of NVGs is essential to insure comfort and to minimize fatigue. Before any adjustment is made to the headstraps which attach the goggles to the

helmet, it is essential that the helmet be properly fitted to your head. When adjusting the helmet, it should be positioned on the head where it will be worn with the night vision goggles. If this procedure is not followed, the headbands and nape strap will be uncomfortable and the helmet may rotate forward and cause the goggles to tip down. As a result, the head must be elevated. This unusual position creates fatigue and distracts from your ability to perform terrain flight.

A variety of headstraps are available with each set of night vision goggles. The aviator headstraps provide three attaching points to the helmet. The SPH-4 helmet is not configured for external attachment of the goggles. Two male snaps and two 2-inch velcro strips must be attached to the helmet. Material and instructions for preparing the helmet are enclosed in the case with the NVGs. Instructions are based on a medium size helmet; other sizes may require modification. There are not enough snaps and velcro strips to configure all the helmets of assigned aviators in an aviation unit; therefore, they must be requisitioned through normal supply channels. The following information is required to obtain the material:

Nomenclature
NSN

Stud
5325-00-285-6295
(quantity of issue, 1 each)

Fastener Tape Hook (Velcro)
8315-00-151-6479
(quantity of issue, yard)

NOTE: It will be difficult to fit the NVGs to helmets smaller than size 6 3/8.

ENVIRONMENTAL CONSIDERATIONS

An awareness of environmental conditions that affect the use of NVGs is essential to insure reliable performance of the goggles. The following preventive measures should be used when the specific environmental condition prevails:

☐ There is a tendency for moisture to form on the eyepieces when they are initially placed on the head. This condition is caused by heat and moisture given off by the body. It is more noticeable during cold temperatures when there is a significant temperature differential between the goggles and the body. De-misting shields are provided to prevent accumulation of moisture on the lenses. Anti-misting chemicals or chemically treated cloths should not be used on the de-misting shield or lenses due to the probability of scratching them.

☐ Aviation usage of NVGs normally does not require the user to operate the goggles in freezing temperatures; however, if it does become necessary, the arctic kit battery holder should be used. This device allows you to operate the goggles with the battery inside your pocket where it is protected from cold temperatures.

☐ If NVGs are operated in a dusty or sandy area, it is essential that goggles be thoroughly cleaned before placing them in the carrying case.

☐ Exposure of the goggles to a salt water environment can cause corrosion. To prevent deterioration, the goggles should be cleaned with fresh water. Immersion is authorized. Allow to dry before storing.

☐ Operation of goggles during rainy or humid conditions can cause corrosion if not properly cared for. During use, the de-misting shields should be installed. After the mission, the goggles should be dried out. Never store the goggles in a wet carrying case.

MAINTENANCE CONSIDERATIONS

Night vision goggles that are properly maintained will provide the user reliable service. The following maintenance should be performed on the goggles:

☐ Prior to each usage, clean the lenses. A soft tissue should be used when wiping the lenses. Lens cleaning tissues that contain an abrasive material should not be used. The NSN for requisitioning the proper tissue for cleaning the lenses is NSN 6640-00-240-5851 (quantity of issue, 100 each). Water may be used to clean the lenses. A brush with soft bristles can be used to clean out accumulations of dirt on the lenses.

☐ Continuous use of goggles will cause the cushion to become dirty. This area should be cleaned periodically with a mild solution of soap and water. Before wearing or storing the goggles, insure the cushion is dry.

☐ When the goggles are not being worn, the lens covers should be installed. There is a tendency for the user to suspend the goggles from the neck by the safety strap without covering the objective lenses. As a result, the objective lenses are scratched by the buckle on the safety belt. When it is necessary to suspend the goggles from the

neck, but impractical to install the lens covers, the safety strap may be shortened sufficiently to prevent the lens from contacting the safety belt buckle by rotating or twisting the goggles. You should never tie a knot in the safety strap as this prevents removal of the goggles over the helmet.

☐ When installing or removing a battery, insure the selector switch is in the OFF position. If the switch is on, intermittent electrical contact is made when unscrewing or screwing the battery cap, causing a flicker or power surge to the tubes that may cause burn spots on the tubes.

☐ Always store the goggles with the battery removed. There is a possibility of inadvertently turning the switch on when placing them in the case. If goggles are stored for an extended period of time with the battery installed, corrosion can develop.

☐ Rough treatment of the goggles must be avoided. Mistreatment of the goggles may cause a failure of one or both tubes or the electrical system. If the goggles do not operate when the switch is turned on and the battery is fully charged, check the wiring for a broken wire or oxidation at the terminals.

☐ Always dry the goggles after they have been exposed to moisture. Moisture causes the electrical system to oxidize which results in a system failure. Allow sufficient time for the goggles to air dry before storing.

AIRCREW NVG REQUIREMENTS

When conducting night operations with the aid of night vision goggles, each aircrewmember—pilot, copilot/navigator and crewchief when applicable—should wear them. This will insure that each crewmember has the same night vision capability. Disregard for this requirement degrades the aircrew's ability to function as an effective team. Aircrewmembers not equipped with goggles may develop fear and anxiety as a result of not being able to see objects seen by aircrewmembers equipped with goggles.

Before aircrews are authorized to conduct night missions with NVGs, they should have completed a course of instruction prescribed by the US Army Aviation Center. Failure to undergo this instruction before performing operational missions endangers the safety of the aircrew and aircraft. Although the goggles improve your ability to see at night, there are inherent limitations that create an unsafe condition unless you are trained to cope with these problems. Overconfidence in your ability to fly with the goggles without proper training is an invitation to an accident.

AIRCRAFT PREPARATION

The light system for current Army aircraft was not designed for use with the night vision goggles. As a result, the capability of the aircrew to see outside the aircraft with the goggles is degraded. Numerous tests have been conducted to determine what modifications to the aircraft and the lighting system should be made to make the environment more

compatible with the night vision goggles. The project manager for each aircraft has identified and is preparing modification work orders (MWO) to configure the aircraft for night flight. Proposed modifications include—

- ☐ Painting the cockpit interior flat black.
- ☐ Redesign of the interior light control rheostats so that the light's intensity can be reduced to a usable level while maintaining a balance of light conditions for all instruments.
- ☐ Installation of a three-position switch which will allow you to select either of three light intensities for the warning and caution lights—DAY, NIGHT, NVG.
- ☐ Installation of a cockpit illumination. A modification of the standard map light has been proposed which provides sufficient illumination to read the instruments and gages without degradation of imagery.
- ☐ Installation of a rheostat that controls the intensity of the exterior lights.

Each of the above modifications improves the night vision of the aircrew wearing night vision goggles; however, effective training can be accomplished without any of the recommended modifications to the aircraft. Field expedients can be used to restrict interior lights that cannot be controlled by a rheostat—caution and warning lights. Exterior lights can be taped, as required, to reduce the amount of illumination.

**THE AIRCRAFT LIGHTING SYSTEM
DOES NOT PREVENT FLIGHT WITH THE
NIGHT VISION GOGGLES.**

Specific recommendations for preparing each type aircraft for night flight are contained in the "preparation for night flight" series of training circulars. For detailed information, refer to the specific publication relating to your type aircraft.

LESSONS LEARNED

Flight techniques and visual cues used for unaided night flight also apply for aided night flight. The additional advantage of night vision goggles is that ground reference is gained; however, your field of view is significantly reduced. To compensate for the loss of peripheral vision, you must continually scan the area to your front and sides. To view the area of concern, you must rotate the head slowly so that the goggles are pointing in the desired direction. Rapid movement of the head can induce vertigo. Movement of the eyes will not change the viewing perspective. The ability to fly with night vision goggles is not a natural gift. It must be learned through training. The more you fly with night vision goggles, the more you learn about them. As a result, you gain confidence in your ability and the capability of the goggles. Extensive testing and training with the night vision goggles has been conducted. The following information identifies the lessons learned from operating with the night vision goggles.

- ☐ To read the flight instruments or engine gages, it is necessary to focus the goggles for inside viewing. Viewing of the

instruments while in flight requires that you direct your attention inside the aircraft. To avoid this unsafe condition, the copilot should be assigned the responsibility for monitoring the engine instruments. Also greater reliance should be placed on the caution and warning lights to alert the aircrew that a system is malfunctioning.

☐ The airspeed and altitude can be read without refocusing the goggles. By observing the position of the needle and knowing the relative position of each number on the dial, altitude and airspeed information can be accurately estimated. In a similar manner, the engine instruments can be read without refocusing the goggles for inside viewing. By rotating the gages so that the needles are at the 9 o'clock position when the aircraft is operating, you can detect a malfunction if the blur of a needle deviates from this position. When a deviation from normal is observed, refocus for inside viewing to ascertain the extent of the change.

☐ The inability to see color through the goggles may create a problem. A normal cue for identifying an airport or obstruction is a colored light. When viewing colored lights through the goggles, they all have a green tint. Structures and terrain features also appear green in color. To overcome this problem, emphasis must be placed on identification by shape and accuracy of navigation.

☐ Detection of obstruction with small reflective surfaces—wires, tree limbs—is difficult. In most cases, these obstructions are also difficult to detect during the day. The best way to locate wires is to look for the poles. Upon locating the wires,

overflight should be made at the poles supporting the wires.

NOTE: Depth perception and estimation of distances are difficult to determine when viewing through the goggles. As experience and familiarization with the terrain is obtained, less difficulty will be experienced in judging distances. Visual cues in the landing area and objects with vertical development along the route aid in determining height above ground.

☐ Any light source that can be seen in the cockpit with the unaided eye will degrade your ability to see outside the aircraft with the goggles. All interior lights must be turned off when flying with the goggles. Lights that cannot be controlled must be covered with a filter or covered with a light reduction material.

☐ Flight instruments and gages can be read without the aid of aircraft lights when a mid light level or higher exists. The infrared light on the goggles may also be used to illuminate the instruments and gages when it is not desirable to turn on the aircraft interior lights. Only one set of goggles in the aircraft should have the infrared light on at any one time. More than one infrared light creates excessive light in the cockpit and causes shadows and reflection on the windscreen.

☐ Exterior lights aid in terrain interpretation close in to the aircraft; however, these lights degrade your detection capability outside the illuminated area of the lights. To minimize the adverse effects of the exterior lights on your night vision, you should operate the navigational lights in the DIM position and tape the lights as

recommended in the appropriate training circular. Turn the anticollision lights off. Do not turn the landing light/searchlight on during flight.

☐ Exterior lights of other aircraft, when operated in the DIM position, do not degrade your vision through the goggles if separation of approximately 100 meters is maintained. If multi-ship landings are to be conducted where the separation between aircraft is less than 100 meters, the lights on the lead aircraft must be turned off. Failure to turn the lights off in flight will create an illusion that the aircraft is much closer than it actually is.

NOTE: When aircraft are landed within 100 meters of each other, the position lights of those aircraft on the ground should be turned off. If a landing is made in an area where aircraft are on the ground with position lights on, the aircrew may lose sight of ground reference due to the effect of the light source on the goggles.

☐ The lights in the standard tactical lighting set are too bright for the goggles when landing to a lighted helipad. A filter must be placed over the clear lens cover. If a filter is not available, the lens cover can be painted or covered with masking tape to reduce the light intensity. In tests conducted by training units, the standard blue lens with one coat of flat black paint was used. This configuration provided the best filtering for most ambient light conditions.

☐ The light intensity of a missile motor will initially prevent you from seeing the

target. After it moves downrange, target identification improves. Procedures for firing the TOW missile with the night vision goggles are contained in FM 17-40.

☐ When firing the 2.75-inch folding fin aerial rocket (FFAR), you will experience a momentary loss of sight with the target; however, after the rockets leave the launcher you will immediately regain sight with the target. No impairment to vision is experienced when firing the 40mm grenade launcher or the 20mm cannon. When firing the machinegun, loss of sight with the target is experienced for the duration of the firing sequence. Refer to FM 17-40 for more detailed information pertaining to weapons firing with the aid of night vision goggles.

☐ During certain conditions, the goggles will allow you to fly, when restrictions to visibility—rain, fog, haze—exist without any significant degradation of imagery. This capability can be a disadvantage in that you may enter IMC unknowingly. When you suspect restriction to visibility exists, remove the goggles to evaluate the condition. As the density of the restriction increases, the light intensity within the goggles will decrease and visual acuity becomes poor.

☐ When parking the aircraft in an area where tactical lighting for night vision goggles is being used, ground guides should be available to direct the aircrew to the parking spot. Night vision goggles should not be removed until the aircraft is sitting on the desired parking spot. The flashlights used by the ground guide must be modified to reduce the light intensity.

☐ Aircrews returning to flight facilities that are not properly prepared for night

landing with the night vision goggles should remove the goggles before landing. This may be accomplished by landing at a tactical site or while en route to the base field. The goggles should not be removed in flight unless sufficient altitude and sufficient time to night-adapt before landing can be assured. Tactical sites should be established where the aircraft can be landed prior to beginning NVG training. At these locations, the aircrewmembers can prepare the aircraft for night flight, and put on their goggles at this time.

☐ Each aircrewmember wearing the night vision goggles should carry one or more extra batteries. This battery should be placed in a position that is easily accessible to the user while in flight. Each user must be proficient in changing the battery in the dark with the goggles on the user's head.

☐ Your night flying proficiency will not improve appreciably using the night vision goggles if you are unable to perform unaided night flight. Aviators who cannot satisfactorily complete unaided training should not be considered for night vision goggle training.

☐ Flight proficiency with the night vision goggles can only be maintained through a training program that requires regular usage. If you do not fly with the goggles regularly, you should undergo refresher training before conducting an operational mission.

☐ It is difficult to read a tactical map with the night vision goggles. In order to read the map, the goggles must be focused for closeup viewing. Changing the focus requires time and prevents the person from

viewing outside the aircraft. Also, the vibrations of the aircraft cause the map to be out of focus. The map itself is not designed for use with the goggles. It is cluttered with symbology that has very little meaning for night flight. To reduce the requirement to refer to the map, the aircrew must become very familiar with the route to be flown. This is referred to as short-term memory navigation.

☐ Instrument flight can be conducted wearing the goggles with the interior lights set at the light intensity level required for unaided vision. Both tubes of the goggles must be focused for inside viewing. Vision outside the aircraft will be restricted due to the high level of light within the cockpit.

☐ Maneuvers requiring bank angles of 30° or more tend to induce spatial disorientation. To avoid this unsafe condition, bank angles should be limited to 30° or less.

NOTE: The self-imposed limitations mentioned for unaided night flight also limit your capability to conduct aided night flight. Aircrews must strive to avoid these self-imposed limitations if the maximum advantage gained by the night vision goggles is to be attained.

GROUNDSPPEED LIMITATIONS

An understanding of the relationship between the detection range capability of night vision goggles (NVG) and the airspeed that will permit the execution of an evasive maneuver once an obstacle is detected is required before flying with the goggles.

The maximum safe airspeed for flying with the goggles is based on the ambient light level, visibility, and the degree of contrast between an object and its background. Figure 6-27 provides a method for the aviator to determine the maximum range that an object can be identified. The range limitation graph considers four conditions of visibility and contrast. They are:

- ☐ 1/4-mile visibility with poor contrast.
- ☐ 1/4-mile visibility with good contrast.
- ☐ 3-mile visibility with poor contrast.
- ☐ 3-mile visibility with good contrast.

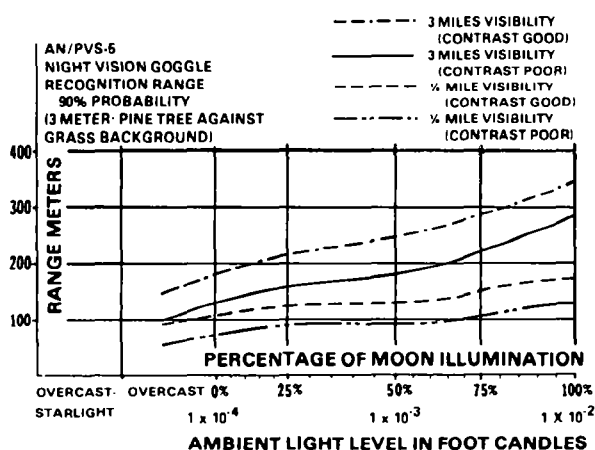


FIGURE 6-27. AN/PVS-5 RANGE IDENTIFICATION.

NOTE: To obtain reliable data from the range limitation graph, the moon altitude must be 30° or greater above the horizon and no cloud coverage.

To determine the range at which an object can be identified, enter the NVG airspeed identification graph along the bottom at the point representing the percentage of moon illumination for the

desired date. Move up until intercepting the visibility and contrast curve for the condition of flight. The range an object can be identified is read to the left.

EXAMPLE:

Percent illumination 25%

Visibility contrast 3 miles (good)

NVG range 220 meters

After computing the range at which an object can be identified, the AN/PVS-5 groundspeed limitation graph (fig 6-28) is used to determine a safe speed for flying with the goggles. Enter the graph along the left side at the predetermined detection range. Move right until intercepting the desired response time. Consideration for selection of either the 5- or 10- second response time is based on pilot proficiency and the groundspeed of the helicopter. From the intersection on the desired response curve, move down and read the safe groundspeed for flying with the night vision goggles.

EXAMPLE:

Detection distance 220 meters

Response time 5 seconds

Safe groundspeed 70 knots

EMERGENCY PROCEDURES

During a night mission, an emergency may occur with the goggles that requires immediate action be initiated to insure the

safety of the aircrew and aircraft. Specific emergencies that are applicable to the night vision goggles include entry into IMC and failure of the goggles.

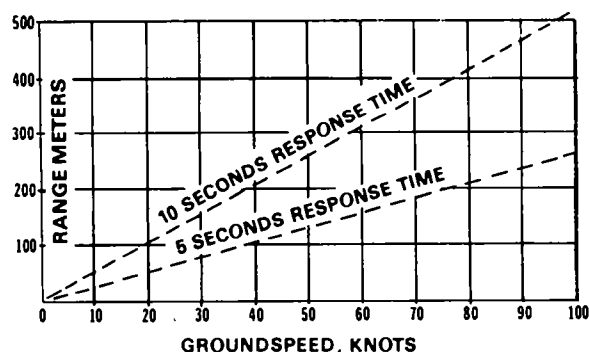


FIGURE 6-28. AN/PVS-5 GROUND SPEED LIMITATION.

□ The most common failure of the goggles is the loss of electrical current caused by a weak battery. When this condition exists, one or both tubes will flicker or the tubes will begin to dim. Upon detection of either condition, you should notify the copilot of your problem and exchange control of the aircraft. Immediately remove the old battery from the goggles and replace it with a new battery. A spare battery must be kept where it is readily available—shirt pocket, flight vest. If this action corrects the problem, continue the mission; if not, remove the goggles and continue the flight using unaided vision.

□ Entry into IMC may not be detected upon encountering these conditions due to the capability of the goggles to see through light fog, rain, haze, and smoke. A gradual reduction of light and poor visual acuity will be experienced as the density of the visibility restriction increases. Upon recognition that you are flying in an area

where visibility is restricted, attempt to determine the severity of the condition. If flight can be conducted using the goggles, continue the flight. If visual flight cannot be performed, execute IMC recovery procedures. This will require that the pilot focus one lens to the flight instruments, while maintaining control of the aircraft and initiating a climb; meanwhile, the copilot will remove his goggles and turn on his flight instrument light. After this is accomplished, he will take control of the aircraft and continue the flight using unaided vision. The pilot may retain his goggles or transition to unaided vision as the situation dictates. Due to the ability of the goggles to penetrate most obscurations to visibility in a tactical environment, it may be advisable to retain the goggles until the approach is complete.

FUTURE DEVELOPMENTS

Combat developers realize the current production model of the night vision goggles does not fully satisfy the needs of the Army aviator for conducting terrain flight at night. As a result, a third generation of goggles is being developed. The initial production model of the new goggles is expected to be available for testing in the near future. It is anticipated that the improved goggles will increase Army aviation units' capability to operate at night. The following design features and capabilities will be incorporated into the new night vision goggles.

□ The goggles are attached to a headband type device that fits on the head inside the helmet. This feature eliminates attaching the goggles to the helmet and reduces neck fatigue.

☐ Incorporated within the mounting bracket is a flip-up device that allows the user to raise the goggles out of his field of view. This allows him to transition from aided to unaided vision and vice versa while maintaining control of the aircraft.

☐ The weight of the device will be reduced approximately 50 percent. This design feature will improve the comfort of the goggles and reduce neck fatigue.

☐ The distance the tubes (arm) protrude out from the face will be shortened. This improvement is realized through the design of the mounting device.

☐ The sensitivity of the improved goggles to light will be greatly increased. It is anticipated that the ambient light from stars may be sufficient to perform terrain

flight. This improved capability will enable you to see with greater clarity. Obstructions that were difficult to detect during mid light levels—wires, barren tree branches—should be more easily identified at greater distances.

☐ When viewing through the goggles, the user will be able to use his peripheral vision to see objects outside the field of view of the goggles. This capability is possible due to the design of the binocular assembly housing and the head mounting device.

☐ Although not in the final stage of development, a design feature will be incorporated which will allow the user to view the gages and instruments within the cockpit without refocusing for closeup viewing.

SECTION VII

TRAINING

TRAINING CONSIDERATIONS

Aviation unit commanders are responsible for conducting both aided and unaided night training. The course of instruction must instill confidence and maintain the interest of the students. Because night flying is hazardous, emphasis must be placed on preflight planning and teamwork between aircrewmembers. To attain the greatest effort from the student and instructor pilot when engaged in night flight training, the following guidelines are recommended:

☐ Due to the increased stress of night flight, especially during night vision goggle training, fatigue is greatly increased. To prevent unsafe conditions, IPs conducting NVG and tactical night training should be restricted to 3 hours of instruction within a 24-hour period. Also, the work period should not exceed 8 continuous hours within a 24-hour period. It is essential that

the instructor pilot use his off time to obtain adequate rest prior to reporting to the flight line.

☐ The student also experiences greater fatigue in night flight; therefore, he must be given sufficient time to rest prior to and after night flight training. The student work period should not exceed 8 continuous hours within a 24-hour period.

☐ When introducing the student to night terrain flight, both aided and unaided, insure a high light level prevails. This allows the student to become acclimated to night environment at low altitudes when visual cues can easily be seen and it reduces stress and anxiety. The first training period should be of short duration to avoid overfatigue. As the student progresses, training should be conducted during lower light levels and the training period may reach 1 1/2 hours in duration. It is not felt the student benefits by introducing terrain flight training at altitudes above 200 feet AGL.

☐ Weather minimums during which training can be conducted must be established. It is recommended that the ceiling and visibility be forecast at least 1,000 feet and 3 miles in the immediate training area for a period of 1 hour prior to arrival until 1 hour after termination of training. When

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conducting terrain flight training, cloud coverage should not exceed a scattered condition. If the actual weather condition deteriorates below the established minimums during the training period, night training should cease.

☐ Night terrain flight cannot be performed safely during all hours of the night. The percentage of illumination and the altitude of the moon will dictate when safe terrain flight can be conducted. Although conditions will vary based on the type of terrain, it is recommended no night flight training be conducted when the moon condition is less than 20 percent moon illumination within 30° of the horizon.

SUPPORT REQUIREMENTS

Success of night training programs is based on the support provided before, during, and after completion of the flight period. Failure to provide the required support can result in an unsafe training environment. Support requirements for conducting night flight training are as follows:

☐ *Numerous flight routes must be made available.* Consideration must be given to avoiding obstructions and built-up areas where there are many lights. The day NOE course may be acceptable; however, the course should be checked at night for presence of lights along the route. Prior to night training, the route should be flown during the day to check for obstructions that may have appeared since the last flight. A hazard map should be posted in the briefing room. Every aviator has the responsibility for updating the map when a new obstruction is detected.

☐ *The airfield lighting system must be configured for night training.* If the primary field is not equipped with proper lighting, a tactical site/stagefield must be made available. Tactical lights for aided and unaided vision are required when operating at a tactical site.

☐ *A safety and control aircraft must be in the air during training.* A crash rescue team consisting of a rescue aircraft and fire truck with crews should also be available on a standby basis. The aircrew must be qualified in unaided and aided night flight and familiar with the routes being flown. Night vision goggles will be available to the aircrew of the safety and control aircraft. Responsibilities of the aircrew include:

- Stopping training any time communications, safety, and weather criteria are not met.

- Directing crash-rescue personnel in case of a downed aircraft.

- Insuring aircraft separation during training and performing flight-following functions.

NOTE: A survival radio should be available for each aircrew conducting night tactical training and for the safety and control aircrew.

TRAINING EQUIPMENT

The capability to conduct realistic night training during low ambient light conditions is the goal of Army developers. This

capability enables aviation unit commanders to train assigned personnel at less cost without the limitations imposed by the moon phasing angle. New and innovative pieces of equipment are being developed to achieve the goal. The systems being evaluated for night training are covered below.

☐ A daytime night vision goggle has been developed which will enable the aircrew to conduct simulated night flight during daylight hours. Filters of varying neutral densities can be attached to the objective lens. These filters reduce light level before light enters the tubes, thus simulating a night environment. A shortcoming of this system is that it does not duplicate what would be experienced at night when viewing lights.

☐ The synthetic flight trainer system (SFTS) can be used effectively to teach NVG emergency procedures and instrument flight with the goggles on. When conducting flight using the NVGs in the SFTS, cover the windows to reduce the amount of light entering the cockpit.

☐ The pink filter has been used successfully as an illuminator during periods of low ambient light. This system consists of a filter mounted on the landing light. Additional testing is being conducted to determine if it is cost-effective.

☐ A white light defuser has been developed—and should be available in the

near future—which increases your ability to perceive objects within the area illuminated by the landing light/searchlight. When viewing an area illuminated by the standard landing light/searchlight, you can only see objects within the high light area or 25 percent of the area being illuminated. Objects within the entire area illuminated by the white light defuser can be seen without any limitations.

☐ Aircraft equipped with a high intensity light has been used to illuminate the area in front of the training aircraft. This system is used during low light levels in order to conduct training when the moon phasing angle precludes effective training.

FLIGHT TRAINING FOR NIGHT FLIGHT

Night training should be conducted in two phases. The *first* phase should consist of that training required to qualify the aviator in unaided night flight. This training consists of basic night flying skills and advanced terrain flight. The *second* phase consists of training the aviator to conduct terrain flight using night vision goggles. An exportable night training package is being developed at the Aviation Center that will be available for distribution to the field in the near timeframe. This package will contain a recommended course of instruction for both unaided and aided night flight training and other aids that will help units training personnel to establish an effective night training program.



CHAPTER 7

EXTERNAL LOAD
OPERATIONS

PREFLIGHT PROCEDURES

The two basic modes of cargo are *internal* and *external* loads. Only the external load will be discussed here. Before flying an external load, an aviator must take several factors into consideration.

☐ *External Load.* All external loads are divided into three basic categories: high density, low density, and aerodynamic. Each exhibits different characteristics in

flight. The high density load offers the best stability; the low density load is the least stable. The aerodynamic load exhibits both instability and stability (instability inherent until load streamlining occurs). The aviator must determine the category, size, and weight of the load during the preflight phase of the operation.

☐ *Cargo Nets and Slings.* Cargo nets and slings are an essential part of the external load operation, and must be given the same attention during preflight inspection that the cargo receives. Any evidence of frayed or cut webbing is justification for replacing the component. Because of the critical strength requirements, field sewing of nylon should not be attempted; nor should nonstandard parts be substituted in assembling slings. The sling assembly must be commensurate with load requirements; and it must meet the requirements in the Operator's Manual for the aircraft in use.

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☐ *Operator's Manual.* Prior to sling load operations, the aviator must consult the appropriate Operator's Manual. Performance charts in this manual include gross weight limitations, airspeed limitations, and endurance charts. The gross weight chart provides a rapid means of determining the load-carrying capabilities of the aircraft within safe operating limits. The Operator's Manual also gives a complete operational explanation of the sling release systems. During preflight, the aviator must inspect the emergency release systems and make an operational check of all normal release modes. Emergency procedures for any nonstandard occurrence which might be experienced during external load operations are outlined in the Operator's Manual.

CAUTION: In extremely cold climates, structural limits can be exceeded without exceeding performance limitations.

☐ *Coordination With Flight and Ground Personnel.* The preflight is not complete until the aviator has briefed his flightcrew and the ground crew on their duties and the mission to be performed. Essential criteria for a safe operation must be fixed in each man's thinking prior to the operation. Included in this criteria are signaling procedures in accordance with unit SOPs and emergency procedures covering all phases of the operation. Basic signaling may incorporate the use of radios, hand signals, colored smoke, and flags or panels. Any combination of signals may be used in a separate external load operation.

PICKUP PROCEDURES

Pickup technique varies according to the helicopter in use, type and weight of the external load, terrain involved, and wind and weather conditions at the time of pickup.

☐ *Approaching the Load.* Normally, the approach to hookup is conducted into the wind, yielding best aircraft stability. A slow forward hover allows the aviator to receive directions from the flightcrew and ground personnel without jeopardizing the aircraft or hookupman's safety. When directions are received solely from ground personnel, a signalman must position himself in plain view of the aviator and give appropriate visual signals throughout the operation.

☐ *Hover Altitude.* The appropriate hover altitude is dependent upon several variables. These variables include the type of helicopter used, terrain and ground effect, size of the load, and safety of the ground crewmen. Once an altitude is decided, it should be kept constant to prevent false perception and possible load strikes. References should be selected in the front and to the sides of the helicopter that will assist in maintaining a constant hover altitude and position over the load.

☐ *Hookup Procedure.* Hookup commences with final positioning of the helicopter over the load. In cargo type helicopters, this is normally conducted through verbal coordination with a flight crewman (crew engineer) who is in a position to closely observe the helicopter's movements over the load. In helicopters

that do not permit flightcrews to observe the helicopter's movements over the load, a signalman located on the ground and in plain view of the aviator, must be used. In all cases, the signals (verbal or visual) must be standardized among the persons involved prior to the operation. (See "Preflight Procedures.") The load is attached to the helicopter's cargo hook by the hookup crew when the helicopter is stabilized in close proximity to the load. In the event an emergency condition occurs while hovering over the load and the helicopter must be landed, hookup personnel will move in the opposite direction the helicopter is being landed. This procedure will be established by unit SOP and all personnel will be briefed by the pilot before conducting external load operations. The hookupman will enter from the right and exit to the right. During hookup, ground personnel should never position themselves between the load and the helicopter. Attaching procedure will be in accordance with the appropriate Operator's Manual, TM 55-450-11, TM 55-450-18, TM 55-450-19 and unit SOPs. The aviator in control is notified immediately when the load is attached to the cargo hook. Any emergency procedure following attachment must include cargo release.

WARNING: If the aviator activates the FM radio transmitter button during ground crew initial contact with the cargo hook, it *may* discharge some static electricity. However, the static electric charge builds up again almost instantaneously following discharge. Therefore, a grounding device should be used to discharge static electricity.

☐ *Takeoff Procedure.* When taking off with an external load, two distinct phases are:

- *Lifting the load to a hover.* Once the load is fixed to the helicopter, the aviator initiates a slow vertical ascent until the sling becomes taut and centered (close coordination should be maintained between the aviator, flightcrew, and/or ground crew to insure the aircraft does not drift from over the load). The load is then lifted to an appropriate hover altitude. At a hover, the aviator must determine whether the helicopter has available power to continue the operation. Also while at a hover, the security and proper rigging of the load is reconfirmed.

- *Takeoff.* If all criteria have been met for flight, a smooth acceleration and takeoff are initiated commensurate with operating limitations of the helicopter. Sufficient power (not to exceed maximum allowable) must be applied on takeoff to insure that the load clears all obstacles by a safe altitude. Once established at a safe altitude, power should be adjusted to maintain a safe airspeed and altitude.

NOTE: A safe climb altitude is the altitude wherein the load is unquestionably clear of the highest barrier—usually 50 to 100 feet above the tallest immediate obstacle.

AIRCRAFT PERFORMANCE

Low density, light loads generally tend to shift further aft as airspeed is increased and may become unstable. When the load is of greater density, more compact, and balanced, the ride is steadier and the airspeed may be safely increased. Any

unstable load may jump, oscillate, or rotate, resulting in loss of control and undue stress on the helicopter. This requires reducing forward airspeed immediately, regaining control, and "steading up" the cargo load. If an external load begins oscillating fore and aft, the helicopter should be started into a shallow bank while decreasing airspeed. This will normally shift the oscillation laterally, which can be easily controlled by further decreasing forward airspeed. The weight and density of the load may determine airworthiness (steadiness in flight) and the maximum airspeed at which the helicopter may be safely flown. At the first indication of a buildup in oscillation, it is mandatory to slow the airspeed immediately because the oscillation may endanger the helicopter and personnel, and may necessitate jettisoning the load. For a complete explanation of the release system for the helicopter to be flown, see the Operator's Manual.

INFLIGHT PROCEDURES AND CHARACTERISTICS

Flight characteristics and helicopter performance with external loads are dictated by various load configurations as discussed previously.

TERMINATION AND RELEASE PROCEDURE

Termination and subsequent load release must include:

☐ *Approach to Termination Point.* The approach to termination should not be

initiated until the appropriate delivery point is identified. Factors affecting the approach will not be constant. An aviator should attempt to plan an external load approach into the wind, using a normal approach angle, and terminating at a hover short of the release point in plain view of the ground crew signalman.

☐ *Hovering to Load Release Point.* Procedure to the release point will be accomplished in the same manner as described earlier; however, the procedure reverses over the release point.

☐ *Releasing the Load.* When the helicopter has stabilized over the load and has slack in the sling, the cargo hook is opened. Usually the cargo hook is opened through the normal release modes of operation. (See appropriate aircraft Operator's Manual.) Emergency or manual release is attempted when normal modes fail to function properly. If the cargo cannot be released by the flightcrew from the helicopter, ground personnel in accordance with SOP and other directives, may use any means necessary to free the load. These methods might include the use of knives, bayonets, or blade-like instruments to cut nylon or rope components of the sling assembly. When metal components must be cut to free a load, devices such as diagonal cutters, bolt cutters, pliers, or cable cutters are appropriate.

DUTIES OF GROUND CREW

☐ *General.* The ground crew normally consists of three men—the signalman and two hookupmen. However, if the situation demands one man may serve as the hookup crew. The transported unit is responsible for providing the ground crew personnel for helicopter external load operations. These crews should be properly trained and kept abreast of developments on new equipment and operational techniques and procedures. When performing external load operations, they should wear goggles to prevent injury. Ground crews should be briefed by the aviation representative who is familiar with the mission to be performed. The ground crew must:

- Be familiar with the type of cargo to be transported.

- Direct the planning of the cargo load for hookup.

- Inspect the load to insure that the slings are not fouled and the load is secured and ready for hookup.

- Insure that the area to be used is clear of any obstructions.

- Insure that cargo weight does not exceed the capability of the helicopter, load, sling, or cargo net.

- Insure that the hookup area is clear of all objects that might be blown by helicopter rotorwash, thus endangering ground personnel and causing damage to aircraft.

- Be familiar with helicopter hand signals for both day and night operations.

- Insure that no illumination device on the ground may be set off by helicopter downwash during night operations.

WARNING: The sling load must not be rigged in a manner that could limit the helicopter's maneuver capabilities. An improperly rigged load could cause the helicopter to be pulled into an unrecoverable attitude by strong crosswinds or turbulence.

☐ *Duties of Signalman.*

- As the helicopter approaches the hookup area, the signalman takes a position about 15 meters (50 feet) beyond and upwind from the load, facing the load with his arms raised above his head. His position must be such that the aviator can plan his approach on him; the signalman must remain in view of the aviator during the entire hookup and departure process.

- As the helicopter approaches the load, the signalman positions himself approximately 45° off the aviator's side of the helicopter, remaining approximately 15 meters (50 feet) away from the load.

- After the helicopter has come to a hover, the signalman guides the aviator directly over the load for hookup. (All signals must be precise, with no unnecessary movements.)

- After the hookup is completed, the signalman signals the aviator that the load is securely attached. He then gives the hookupmen sufficient time to clear from beneath the helicopter before giving the aviator the signals to center over the load.

- As the helicopter moves upward, the signalman insures that the load is properly secured and that the cargo is properly suspended.

- The signalman then gives the aviator the takeoff signal and moves quickly aside to be clear of the takeoff path.

☐ *Duties of Hookupmen.*

- As the helicopter hovers over the sling load, the hookupmen will position themselves next to the cargo to prepare for hookup. Their position should be one from which the hookup can be accomplished quickly and easily; and they will remain in plain view of the signalman at all times.

- After the hookup, the hookupmen must insure that the cargo hook is properly secured; then move quickly from beneath the helicopter and out of the takeoff path.

CAUTION: Hookup personnel should be aware of the buildup of static electricity on the helicopter. Before making contact with the cargo hook, they should use a grounding device to discharge the static electricity.

CHAPTER 8

RESCUE HOIST OPERATIONS

UH-1 AND CH-47 SERIES HELICOPTER RESCUE HOIST SYSTEMS

Although the techniques and procedures for a specific rescue hoist operation will vary according to the type of helicopter and hoist system used, the same basic principles are employed for all helicopter rescue hoist operations. Detailed descriptions and operating instructions for the UH-1 and CH-47 series helicopter rescue hoist systems are contained in the appropriate TM 55-series-10 (Operator's Manual).

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□ The *UH-1 rescue hoist system* (fig 8-1) consists of a vertical column extending from the floor structure to the cabin roof, a boom with an electrically powered traction sheave, and an electrically operated winch. It can be installed in any one of four alternate locations in the helicopter's cabin. When only the pilot is at the controls, the hoist should be installed on the opposite side of the helicopter to allow the pilot to observe the actions of the hoist operator. However, when both a pilot and copilot are available, the hoist is installed behind the pilot's (right seat) position to allow the copilot to monitor the hoist operator's actions. Normally, the UH-1 rescue hoist is used for one survivor at a time to prevent an adverse effect on the helicopter center of gravity. Figure 8-1 shows the UH-1 rescue system with the forest penetrator seat assembly attached.

● The hoist is operated by the hoist operator's pendant control or by controls on the right hand (pilot's) cyclic stick.

● The hoist has a maximum lifting capacity of 600 pounds; however, the actual load may be reduced by its position in the helicopter due to weight and balance limitations. See chapter 6 of the appropriate aircraft Operator's Manual.

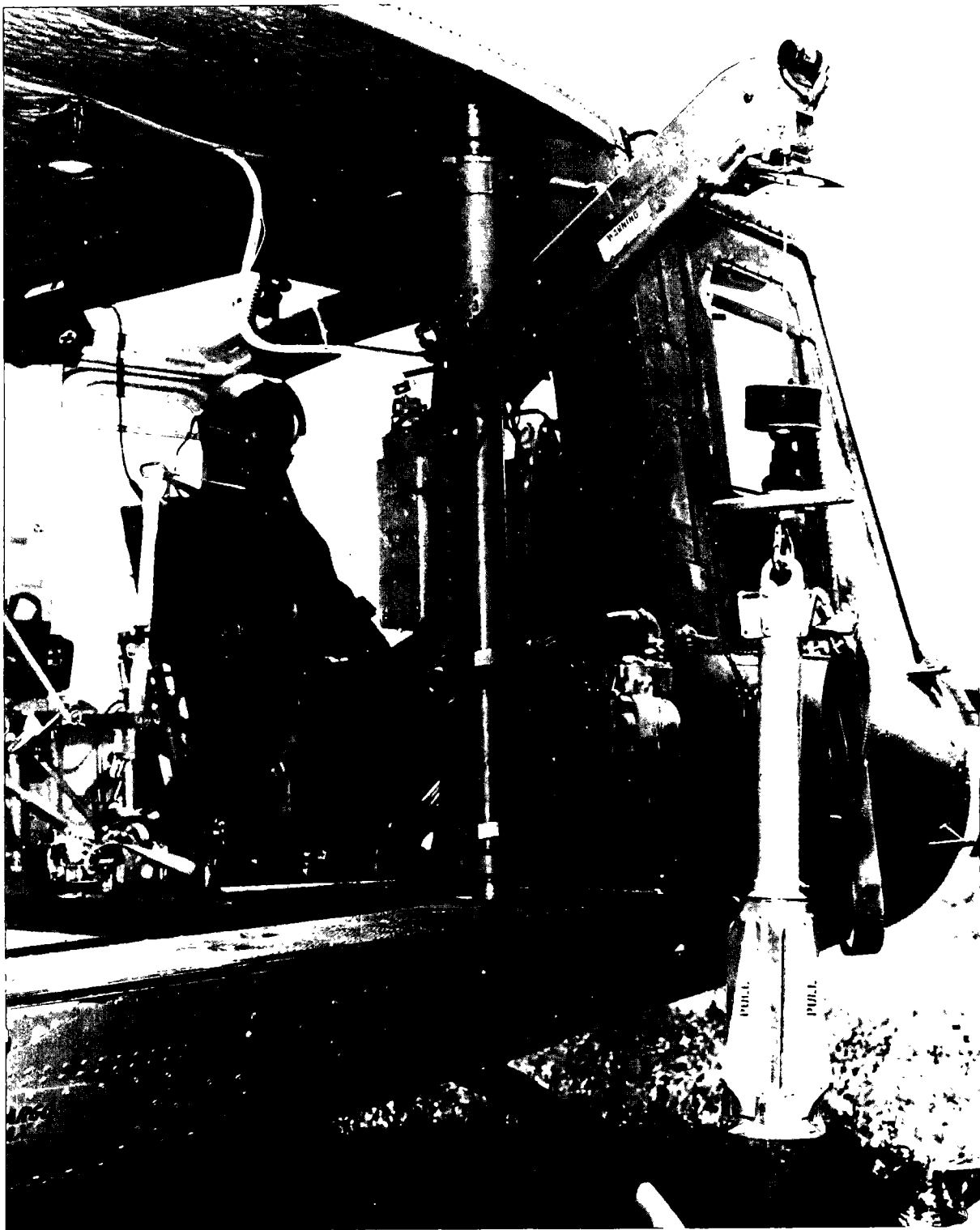


FIGURE 8-1. UH-1 RESCUE HOIST SYSTEM
WITH FOREST PENETRATOR ATTACHED.

- The usable cable length of the hoist is 256 feet and the entire length is color coded. The first 25 feet are color coded yellow; the next 175 feet are unpainted; the next 40 feet are yellow; and the last 16 feet are red.

- To cut the cable free of the helicopter in an emergency, the pilot's cable cutter switch is mounted on the pedestal and the hoist operator's cable cutter switch is mounted on top of the control box.

- The pilot's controls override the hoist operator's controls.

□ The *CH-47 rescue hoist system* (fig 8-2) has a permanently mounted, hydraulically operated winch. A selector control lever on the cable drum housing provides two reeling speeds. For hoisting, the selector control lever is moved to "RESCUE." The pilot's winch controls are on the overhead switch panel and the hoist operator's controls are on the winch/hoist control grip at the utility hatch. In an

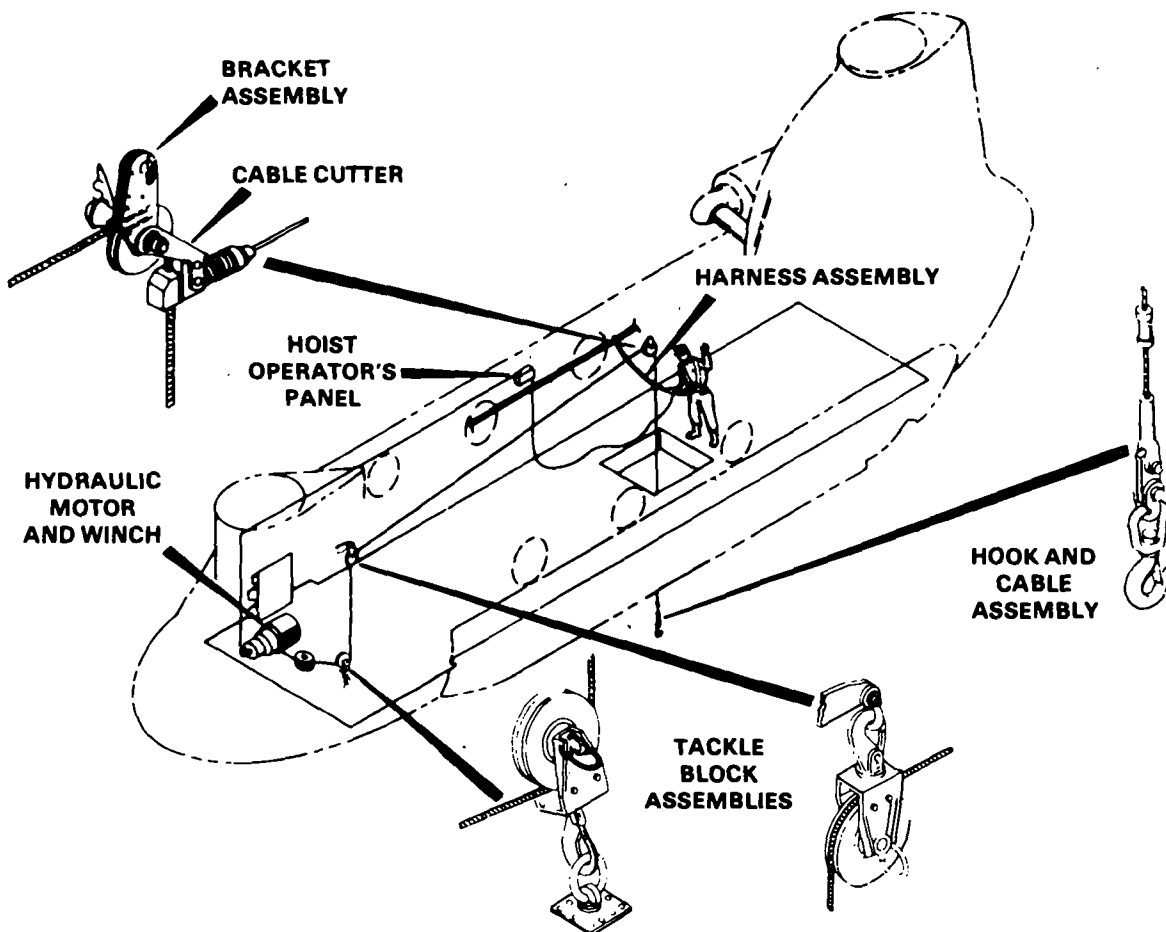


FIGURE 8-2. CH-47 RESCUE HOIST SYSTEM.



FIGURE 8-3. FOREST PENETRATOR IN USE.

emergency, the hoist operator or pilot may operate an electrical cable cutter to cut the cable free of the helicopter. The overhead panel switch overrides the winch/hoist control grip switches. The hoist cable has a usable cable length of 120 feet and a maximum lifting capacity of 600 pounds.

FOREST PENETRATOR

The forest penetrator can be used to lift survivors not requiring the stokes litter discussed below. It is basically a rescue seat with folding prongs and safety straps (fig 8-3) that can lift up to three personnel at one time. However, because of structural limitations, the total weight cannot exceed 600 pounds.

STOKES METAL LITTER

This litter consists of a steel or aluminum tubular frame supporting a bed of wire mesh netting and four straps to secure the survivor. It must be modified with suspension cables for use with the UH-1 rescue hoist system (fig 8-4). The stokes litter cannot be lifted in the horizontal position through the utility hatch in the cargo compartment floor of the CH-47.

CREW RESPONSIBILITIES

The recommended minimum crew for helicopter rescue hoist operations is a pilot, copilot, hoist operator, and medical aidman. Since crew coordination is the key to

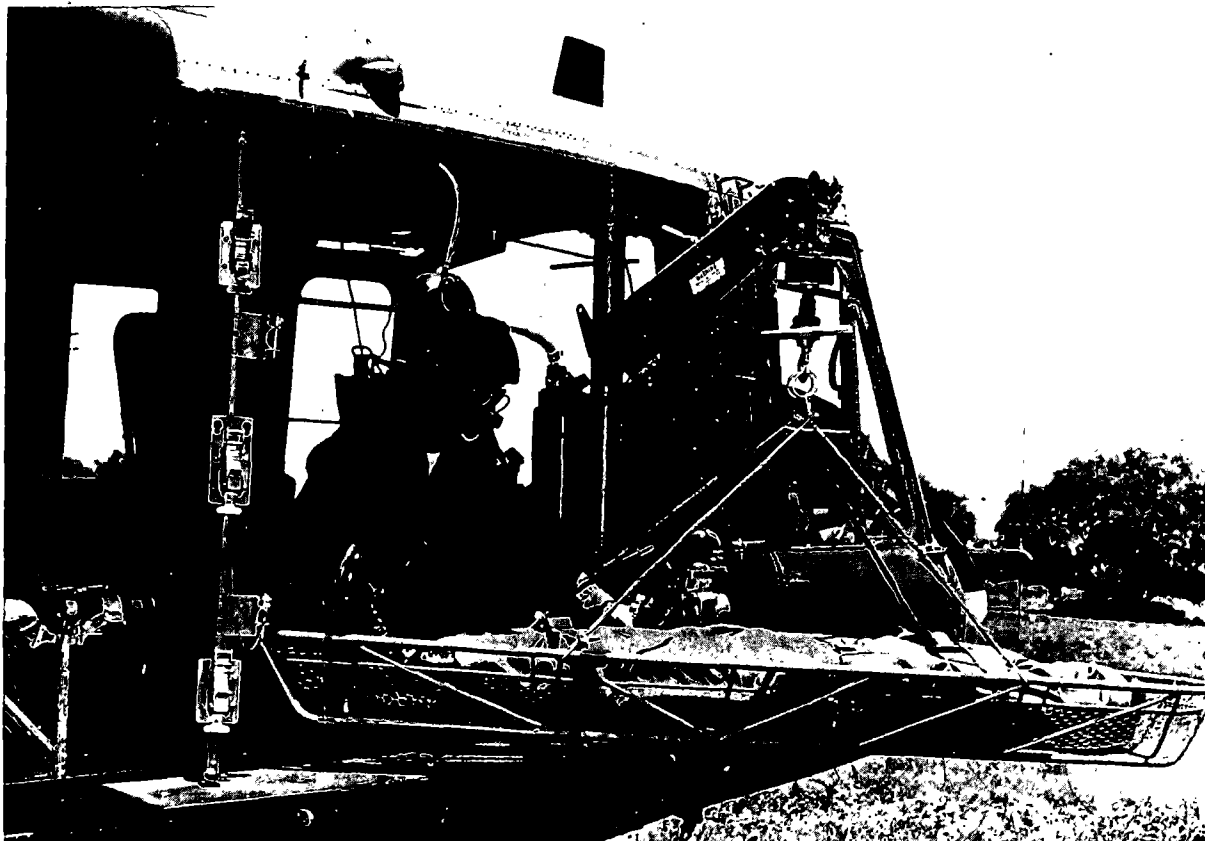


FIGURE 8-4. STOKES METAL LITTER MODIFIED FOR USE WITH UH-1 RESCUE HOIST SYSTEM.

successful hoist operations, each crewmember must thoroughly understand the duties of all other crewmembers. The copilot must be ready to assume the duties of either the pilot or the hoist operator if required. If the survivor is incapacitated, the pilot may designate one crewmember to leave the helicopter by way of the hoist to aid the survivor as discussed later in this chapter. Primary crew responsibilities are as follows:

☐ The pilot has overall command and control of the operation. He supervises planning and preflight procedures and briefs the crew on all details of the mission. He coordinates all crew activities and is responsible for crew proficiency and performance. Although his primary duty is to fly the helicopter, the situation may require him to operate the hoist by using the cockpit controls.

☐ The copilot's main responsibility throughout the operation is to remain oriented and to assist both the pilot and the hoist operator as required. If an emergency condition arises, he will energize the hoist cable cutter switch. He must be familiar with all crewmember tasks and be able to perform the other crewmember's duties if necessary. If the hoist operator is directed to leave the helicopter to aid an incapacitated survivor, the copilot may be required to operate the hoist.

☐ The hoist operator is responsible for inspecting the hoist and all other rescue equipment prior to takeoff, and for insuring that all necessary items are on board the helicopter. His most important duties are to deploy the smoke and flare devices during the smoke deployment phase and to

guide the helicopter over the survivor by means of directional instructions to the pilot during the recovery phase. He operates the hoist during the recovery and assists in lifting the survivor into the helicopter.

☐ The medical aidman's primary responsibility is to provide medical aid to the survivor as needed. He may be required to leave the helicopter to assist an incapacitated survivor. The aidman should be knowledgeable of the operation of the hoist.

INTERCREW COMMUNICATION

The primary means of intercrew communication throughout the operation is voice communication by helicopter interphone system. All crewmembers should use the "HOT MIKE" during rescue hoist operations; however, the pilot or copilot may elect to remain on the command radio and depress the interphone switch. If the interphone fails, hand signals must be used.

☐ *Voice Procedures.* Terminology must be clear and concise and term usage must be completely understood by all crewmembers. To avoid confusion, terms that may apply to either the hoist or the helicopter should be used only in conjunction with the terms "hoist" or "helicopter." Directions should be given in terms of feet. For example, "Left 5, forward 10." Clear communication between the pilot and the hoist operator is critical, especially during the recovery phase. Recommended terms for use during the recovery phase are:

- Direction.
 - Forward/back.
 - Right/left.
 - Up/down.
 - Raise/lower.
- Motion.
 - Slow.
 - Stop.
 - Hold.

☐ *Hand Signals.* If interphone failure occurs, the crew must rely on hand signals for communication. These signals should be preplanned and practiced before the operation. When using hand signals, the pilot and hoist operator should be positioned on opposite sides of the helicopter or the copilot must relay these signals to the pilot. Examples of hand signals that can be used by the hoist operator to direct the pilot during the recovery are:

- Movement of the helicopter—indicated by moving the open hand in the desired direction with the palm facing in that direction.

- Holding the helicopter in its present position—indicated by a clenched fist.

- Movement of the hoist—indicated by extending the thumb either up or down from a clenched fist.

PREFLIGHT PROCEDURES

The appropriate TM 55-series-10 (aircraft Operator's Manual; should be consulted for details of preflight procedures. In addition to the normal preflight procedures required for helicopter operations, the following additional factors must be considered for rescue hoist operations:

☐ Load calculations must allow for an increase in weight due to the additional loading of the survivor and the probability of hovering out-of-ground-effect.

☐ The hoist system should be thoroughly inspected prior to takeoff. Controls should be tested and, when practical, the hoist cable should be fully extended and inspected for kinks and frayed or broken strands.

☐ Rescue devices should be inspected for serviceability.

☐ Personal equipment (e.g., safety harness and protective gloves for the hoist operator) should be checked.

☐ Flotation equipment must be available for all overwater recoveries and must include equipment for the survivor.

☐ All crewmembers should be thoroughly briefed on all aspects of the operation prior to takeoff, and individual duties should be assigned and/or reviewed. All emergency procedures should be thoroughly reviewed.

EMPLOYMENT PHASES

Once the survivor has been located, rescue hoist operations can be broken down into three distinct phases. These are:

☐ *Smoke Deployment Phase.* The *first* phase begins upon sighting the survivor. Smoke is deployed to mark his position and to determine wind direction. If radio communication with the survivor has been established, position marking may not be required. If wind direction is known, other marking devices such as lights or marking panels may be used.

☐ *Pattern Phase.* A flight pattern is established during the *second* phase of the operation to bring the helicopter into position for recovery of the survivor. The type of pattern to be flown will be determined by the position of the pilot in command in the UH-1 cockpit. The left seat provides greater field of vision. However, control of the hoist from the cockpit is only available from the right seat. The unit SOP designates the seat for the pilot in command.

☐ *Recovery Phase.* The *third* phase is the recovery of the survivor. This is the most critical phase of the entire operation and requires the highest degree of crew coordination.

OVERWATER RECOVERY PROCEDURES

Procedures for day overwater recoveries apply also for night operations. (See paragraph entitled "Night Recovery Operations" for additional procedures.)

☐ *Smoke Deployment Phase.* Upon initial sighting of the survivor, a smoke marker device will be deployed in the immediate vicinity to mark the position and to determine wind direction. The survivor must be kept in sight until the initial smoke is dropped. The pilot flies over the survivor as nearly as possible into the wind, and the hoist operator drops the smoke in the vicinity of the survivor. Once the wind direction has been determined, additional smoke and/or flares may be deployed as required to aid in spatial orientation during the recovery phase. The approach should be planned and executed so as to drop the smoke at a slow airspeed and low altitude. The smoke must land in a spot close enough to the survivor to give adequate wind information, but should not obscure his position when approaching into the wind. The pilot must keep the hoist operator continuously informed of the helicopter's position in the pattern at all times during the approach (i.e., on downwind leg, on base leg, and on final approach). The hoist operator advises the pilot when the smoke has been released.

☐ *Pattern Phase.* Once the smoke has been deployed, the pilot plans and establishes a flight pattern that places the helicopter in the proper position for the recovery. If the pilot in command is in the right seat, a right hand pattern should be flown to keep the survivor in sight of the pilot as long as possible. The final approach should permit the helicopter to arrive at a hover far enough from the survivor so that waves are not a hazard to the survivor, and so the rescue device can be lowered into the water while clear of the survivor. The pilot advises the hoist operator of their position throughout the approach and when he has

the survivor in sight. The hoist operator acknowledges all calls and informs the pilot when he has the survivor in sight on final approach. At the completion of the approach and while the hover is being established, both the pilot and copilot devote full attention to maintaining proper altitude, position, and normal operation of engine instruments.

□ *Recovery Phase.*

● Once the hover has been established, the pilot makes a power available check to insure that the helicopter has sufficient power to continue the operation. The altitude at which the check should be performed will be at the lowest altitude possible to conduct the recovery. When the pilot is ready to continue with the recovery, he advises the hoist operator to lower the rescue device and direct the helicopter to the survivor. The hoist operator then lowers the rescue device and gives directional instructions to the pilot to move the helicopter on a straight track to the survivor. Before he loses sight of the survivor, the pilot should transfer his hover reference to the smoke markers that have been placed upwind. He should not attempt to watch the pickup, as spatial disorientation may result. As the helicopter moves slowly toward the survivor, the rescue device should be lowered, making sure it enters the water at least 20 to 30 feet before reaching the survivor. This is to insure that the device does not strike and injure the survivor. Flotation gear will be provided for the survivor at this time if required.

CAUTION: *Static electricity built up on the hoist cable and the rescue device must be discharged by touching the device to the water before attempting the pickup.*

● When the rescue device is in the water and easily accessible to the survivor, the hoist operator directs the pilot to hover in that position. When the survivor is observed to be secure and ready for hoisting, the hoist operator takes up any slack in the cable and notifies the pilot that the pickup is ready to proceed. The pilot then makes a final power check to insure that sufficient power is available for the recovery. The pilot then applies sufficient power to lift the survivor clear of the water approximately 10 feet and then the hoist operator begins hoisting until the survivor is in the cabin.

CAUTION: *The hoist operator should insure that a constant pressure is applied to the cable spool by the traction sheave on the hoist. If this device fails, the operator may be required to apply a pressure. Normally, the hook and handwheel provide sufficient weight to apply the required 5 pounds of tension.*

● During the pickup, using all available references and the hoist operator's instructions, the pilot must devote full attention to maintaining a steady hover. The copilot monitors the instruments and remains oriented with the horizon throughout the operation to assist the pilot should the need arise. The hoist operator's instructions to the pilot must be clear and concise. An example of what the pilot should hear is: SURVIVOR IN SIGHT 50 FEET AHEAD—CORRECT RIGHT—ON COURSE, SURVIVOR STRAIGHT AHEAD—ON COURSE, HOIST GOING DOWN—SURVIVOR STRAIGHT AHEAD—ON COURSE, HOIST HALF-WAY DOWN, SURVIVOR STRAIGHT AHEAD—ON COURSE, HOIST IN THE WATER, SURVIVOR STRAIGHT

AHEAD—ON COURSE, HOIST HALF-WAY DOWN, SURVIVOR STRAIGHT AHEAD—ON COURSE, HOIST IN THE WATER, SURVIVOR STRAIGHT AHEAD—ON COURSE, SURVIVOR 15 FEET AHEAD, SLOW—5, 4, 3, 2, FEET, STOP—OVER SURVIVOR—HOVER. LEFT 5 FEET—STOP, SURVIVOR IN HOIST—READY FOR PICKUP. The hoist operator advises the pilot when the survivor is safely inside the helicopter and secured in the cabin. The pilot then transitions from a hover to forward flight into the wind.

CAUTION: The lateral CG limits may be exceeded if all crewmembers are positioned on the same side of the helicopter.

OVERLAND RECOVERY PROCEDURES

Procedures for overland recoveries apply for both day and night operations:

☐ *Smoke Deployment Phases.* Procedures discussed above for overwater recoveries apply. Determining wind velocity and approximate direction is extremely important to successful hoist operations. Smoke may be used; however, the wind can easily be determined by vegetation in the area. If smoke is used, it should be deployed in an area that is open enough to be seen from anywhere in the hoist pattern. Care should be taken to select a nonflammable target area.

☐ *Pattern Phase.* As in overwater operations, the pattern flown should allow the pilot to maintain visual contact with the survivor. Terrain factors and conditions encountered at the rescue site must be evaluated to determine the best approach to be used. The pilot must keep the hoist

operator informed as to the type of pattern to be flown and the position of the helicopter in the pattern at all times.

☐ *Recovery Phase.*

Ⓢ This is the most *critical* phase of the operation and requires the highest degree of crew coordination. The pilot must devote his full attention to maintaining a steady hover by using all available references and the hoist operator's instructions. The copilot monitors the engine instruments and remains oriented with the horizon throughout the recovery to assist the pilot should the need arise. The presence of trees, wires, or other obstacles will require extreme caution in approaching the survivor. Since all crewmembers must aid the pilot in maintaining rotor tip clearance, all doors and/or ramps will be opened for maximum visibility. The hoist operator must give clear, concise instructions and a continual commentary on the progress of the pickup to the pilot throughout the phase.

CAUTION: Static electricity built up on the hoist cable and rescue device must be discharged by touching the device to the ground before attempting the pickup.

Ⓢ Prior to hoisting the survivor, the hoist operator takes up any slack in the cable and notifies the pilot that the survivor is ready to be picked up. The pilot then makes a final determination that sufficient power is available to safely accomplish the recovery. He may apply sufficient power to lift the survivor clear of the ground approximately 10 feet or the hoist operator will raise the survivor while

at a stationary hover. Both techniques have proven acceptable; however, the first procedure provides the pilot with better control of the helicopter and the survivor is lifted off the ground. The hoist operator advises the pilot when the survivor is safely inside the helicopter and secured in the cabin. The pilot then transitions from a hover to forward flight into the wind.

NIGHT RECOVERY PROCEDURES

In addition to normal day procedures, the following procedures are also necessary:

☐ *Overwater Recoveries.* Due to the problem of spatial disorientation associated with night flight and night hovering over water, continuous flare illumination should be used whenever possible as it provides the best conditions for night recoveries. Flares improve depth perception and reference to the water surface. Multiple smoke or marking devices deployed on the water during overwater recoveries will assist in determining wind direction and will provide a visual reference for hovering. Caution must be used to prevent smoke from restricting visibility in the immediate recovery area.

☐ *Overland Recoveries.* As in night overwater recoveries, flare illumination provides the best possible conditions for conducting night overland pickups. However, it is not absolutely necessary; helicopter lights normally provide adequate lighting to safely accomplish the recovery.

INERT SURVIVOR RECOVERIES

The procedures to be followed for the recovery of an unconscious or inert victim from water or land areas are as follows:

☐ If it is determined that the survivor is unconscious or unable to enter the rescue device, the pilot will direct one of the crewmembers to prepare to exit the helicopter and another to act as hoist operator. If the hoist operator is directed to leave the helicopter, the copilot moves to the cabin to operate the hoist. If a medical aidman is available, he may exit the helicopter while other crew positions remain the same.

☐ The crewmember performing the duties of hoist operator will don the hoist operator's safety harness and assure that the crewmember preparing to leave the helicopter is secured in the rescue device. Flotation gear must be worn during all overwater recoveries and, if necessary, must be provided for the survivor. The pilot is notified when preparations are completed in the cabin.

☐ Once the crewmember is ready to exit the helicopter, he is lowered to the surface where he leaves the rescue device and secures the survivor for hoisting. The hoist operator then notifies the pilot that the hoist operation is ready. The pilot will then determine if adequate power is available to accomplish the recovery.

☐ The pilot applies sufficient power to lift the survivor off the ground approximately 10 feet or the hoist operator will raise the survivor while at a stationary hover. The crewmember acting as hoist operator then hoists the survivor, removes

him from the rescue device into the cabin, and retrieves the crewmember from the surface. The crewmember operating the hoist must keep the pilot informed of the progress of the recovery. When all personnel are safely in the cabin, the pilot is notified. The pilot then transitions from a hover to forward flight into the wind. If the copilot has served as hoist operator, he then moves to his position in the cockpit or remains in the cabin to render assistance as necessary.

CONDITIONS AT RESCUE SITE

Because of the inherent risk, helicopter rescue hoist operations should only be conducted in those situations that preclude safe landing of the helicopter. Before attempting a recovery, the safety of the helicopter crew must be considered. The pilot must evaluate the conditions at the rescue site, such as the presence of obstacles such as trees and wires, and determine whether or not the recovery can be attempted.

HOIST SAFETY FACTORS

The following factors are important to hoist operation safety:

☐ *Free Cable.* The hoist operator must be constantly alert to insure that the cable does not become entangled on immovable objects on the ground or in the water. The entire length of the cable should be kept in view at all times. If the cable does become tangled, an attempt should be made to free it by playing out slack and manipulating the cable. Extreme care should be

used when applying tension to the cable. If the cable should break, whiplash action can cause damage to the helicopter. As a last resort, the pilot may direct that the cable be cut free of the helicopter.

☐ *Avoid Pendulum Action.* Extreme care should be used when hoisting the survivor. If pendulum action and rotation of the survivor are not stopped immediately, the movement may increase to unmanageable proportions. Pendulum action may be dampened by moving the cable in the opposite direction of the survivor's movement. Rotation can be stopped by rotating the cable in a 1- or 2-foot circle in the opposite direction of the rotation of the survivor.

☐ *Bringing Survivor Into Cabin.* The best way to bring the survivor into the UH-1 cabin is to turn his back to the helicopter and then pull him in. This reduces the possibility of a semiconscious or injured survivor fighting the hoist operator. The hoist operator should not detach the rescue device from the survivor or from the hoist cable until the survivor is safely inside the helicopter and clear of the door or hatch. When conducting rescue hoist operations, the hoist operator and aidman should wear safety harness.

☐ *Protective Gloves.* Heavy protective gloves should be worn by the hoist operator to prevent injury to his hands while manipulating the cable.

☐ *Safety Harness Secured.* Before the helicopter door/hatch is opened, the hoist operator should insure that safety harnesses are secured.

EMERGENCY PROCEDURES

All crewmembers are required to know the following helicopter emergency procedures:

☐ *Partial Loss of Power.* If a partial loss of power occurs while hoisting and altitude cannot be maintained, the survivor should immediately be lowered to the surface to lighten the helicopter. If the situation deteriorates to the point where further action is required to prevent settling to the surface, the following action must be taken:

- If hoisting over land, the survivor should first be lowered to the ground and freed from the hoist. It may be necessary to cut the cables as soon as the survivor is safely on the ground. An immediate attempt should be made to recover altitude by lowering the collective pitch lever and/or attaining forward airspeed. Should an inadvertent landing occur, primary consideration should be given to moving away from personnel on the ground. The preflight briefing should cover a pre-planned direction of movement of the helicopter and of any crewmembers that may be on the ground. All personnel on the ground not necessary to the rescue operation must maintain a safe distance from the recovery sites.

- If hoisting over water, the survivor should be lowered into the water and the cable cut to avoid dragging him in the water. An immediate attempt to recover altitude should be made. Should an inadvertent landing occur, primary consideration should be given to moving away from personnel in the water. The pre-planned direction of movement also applies here.

☐ *Complete Loss of Power.* If a complete loss of power occurs, the procedures that should be followed are:

- Pilot—Alert crew and perform emergency autorotation. If possible, the pilot should maneuver the helicopter away from the survivor.

- Hoist operator—Prepare for emergency landing.

☐ *Hoist Failure.* A recovery may be continued if the hoist mechanism fails to raise or lower from the cable extended position. The survivor should be advised of the problem by hand and arm signals and instructed to remain firmly attached to the recovery device. Before entry into forward flight, the helicopter should ascend to an altitude that insures the survivor is clear of all obstacles. With the survivor suspended from the helicopter, recovery may proceed to an area where a safe landing can be made. Flight to the landing area is made at a much slower speed than normal.

WARNING: As pendular action and rotation may become uncontrollable if airspeed becomes too high, extreme care must be used when attempting forward flight with the hoist cable extended with a survivor attached.

During landing with the survivor suspended from the helicopter, extreme care must be exercised to prevent dragging the survivor and entangling the cable in the tail rotor system. The hoist operator and/or pilot must maintain light tension on the cable during landing. After the survivor has been gently lowered to the ground from a vertical descent:

- The emergency cable cutter may be actuated to free the cable from the helicopter to permit landing, or

- The helicopter may be hovered to the side of the survivor and landed with the cable still attached. Then the cable may be detached from the survivor and stored inside the helicopter.

CHAPTER 9

FORMATION FLYING

TERMINOLOGY

The following terminology is used throughout the Armed Services and our Allied NATO Nations.

☐ *Section/Element*—a two- or three-helicopter formation. The two-helicopter section/element is the basic building block for all larger formations.

☐ *Flight/Division*—four or more helicopters in two or more sections/elements.

☐ *Company/Squadron Formation*—a formation of two or more separate flights/divisions. The number of helicopters is determined by the size of the company/squadron.

☐ *Battalion/Wing Formation*—a formation of two or more companies/squadrons.

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DEFINITIONS OF BASIC FORMATION TERMS

□ *Forty-five-degree bearing*—a relative bearing between the nose of the helicopter and the pilot's line-of-sight, right or left, that describes the position of another aircraft in a formation.

□ *Column Formation*—a formation in which all of the largest integral subdivisions (each in identical formation) are positioned one directly behind the other.

□ *Crossover*—the generic term used to describe the movement of a helicopter as it passes laterally above and to the immediate rear of another helicopter during changes of position in a formation.

□ *Echelon Formation*—a formation of aircraft where each succeeding aircraft flies 45° astern of the aircraft in front of it. All aircraft are echeloned on the same side.

□ *Formation (Flying)*—a formation consists of two or more aircraft, holding positions relative to each other, and under the command of a designated aviator therein.

□ *Free Cruise*—free cruise is the technique whereby the wingman maintains a specified distance from the leader, but may vary the bearing from the leader during turns. This distance is measured perpendicular to the lateral line that passes through the tail region of the leader, to the lateral line that passes through the nose region of the wingman. The wingman, as he maintains this distance, is free to maneuver during turns (or if otherwise required) in the airspace extending from 45° on either

side of the leader's tail. In other words, it is said that the wingman owns the airspace extending from 45° on either side of the leader's tail and is free to maneuver through this airspace during turns. This technique applies to section, flight, company, or larger formations.

□ *Hand Signals*—a visual signal or communication made by using the hands and arms. By using the appropriate hand signal, a flight leader can signal the wingman to move from one position to another.

□ *Horizontal Distance and Vertical Separation of Aircraft.*

• Horizontal distance.

■ In a close formation, the horizontal distance between helicopters is normally 2 rotor disk diameters measured between tip-path planes.

■ In a loose formation, the horizontal distance between helicopters is 3 to 6 rotor disk diameters.

■ In an extended formation, the horizontal distance between helicopters may be any required distance in excess of 6 rotor diameters, dependent upon the tactical requirements.

• Vertical separation.

■ Flat (separation)—all helicopters, or all flights of helicopters, are flown at the same altitude.

■ Stepped-up (separation)—vertical separation between the wingman and the section/element leader, measured from the

altitude of the leader upward to the altitude of the wingman.

▪ **Stepped-down (separation)**—vertical separation between the wingman and the section/element leader, measured from the altitude of the leader downward to the altitude of the wingman.

NOTE: The stepped-down formation is never used for helicopter formation flying, because wingmen are likely to experience difficulty in distinguishing the flicker of their own rotor blades from that of the leader, thereby increasing the probability of misjudging interval between aircraft.

☐ **Joinup**—to form separate helicopters into a specific flight formation.

☐ **Lead helicopter; leader**—the helicopter at the head of a helicopter formation and the aviator who flies in the lead helicopter.

☐ **Nose-to-tail distance**—distance from the tail region of a specified formation leader to the blade tip of a particular wingman; or, in multiple formations, the distance from the tail region of one formation to the blade tips of another formation.

☐ **Rendezvous**—a prearranged meeting at a given time and place from which to begin an action or phase of operation, or to which to return after an operation; e.g., to assemble, meet, or arrive at a rendezvous; to meet with another or others in rendezvous.

☐ **Rendezvous and joinup**—to assemble and form into a specific flight formation.

☐ **Staggered trail (left of right)**—a formation in which all aircraft are alternately staggered behind the leader.

☐ **Trail**—a formation in which all aircraft are in single file, each directly behind the other. The aircraft may be flown at the stepped-up position or at the same level.

☐ **Wingman**—an aviator who files at the side and to the rear of, or directly behind a section/element leader, commonly in a two-helicopter or three-helicopter formation; also, the helicopter flown in this position.

FORMATION CONSIDERATIONS

Factors to be considered in determining the best formation to be used in a specific situation include:

☐ **Mission Requirements.**

•Mission of the support unit.

•Mission of the helicopter unit.

☐ **Enemy Considerations.**

•Current enemy situation.

•Enemy antiaircraft and air defense capability.

•Accessibility to enemy visual and/or electronic surveillance.

☐ **Fire Support Plan:**

•Artillery support available.

•LZ preparation planned.

● Air support availability and requirements:

Type aircraft.

Type ordnance.

Naval gun fire (if available).

☐ *Ordnance.* Type ordnance to be used for neutralization fire.

☐ *Terrain and Weather.*

● Configuration of enroute obstacles and/or corridors.

● Size, shape, and surface of the LZ.

● Obstacles in/or affecting approaches to the LZ.

● Ceiling and visibility.

● Winds and turbulence.

☐ *Formation Maneuver and Flexibility.*

● Possible changes in mission or situation.

● Evasive tactics.

☐ *Armed Aerial Escort.*

● Amount of armed escort required.

● Number and type of armed escort helicopters available.

● Position in the formation.

● Mission of the armed helicopters.

☐ *Control of Formation.*

● Degree of control required.

● Method of control (radio, hand signals, prearranged timing, etc.).

☐ *Other Considerations.*

● Type aircraft.

● Crew training and experience.

CREW BRIEFINGS

After selection of the most desirable formation, a great deal of planning and preparation must be completed before the mission takes place. Prior to a formation flight, a detailed briefing should be conducted. This briefing should include, but is not limited to, the following:

☐ Weather.

☐ Route.

☐ Mission.

☐ Interval.

☐ Airspeed.

☐ Radio frequencies and call signs.

☐ Formation.

☐ Emergency procedures.

☐ Terrain conditions.

☐ Altitude.

☐ Maps and charts.

- ☐ Communication check procedure.
- ☐ Communication failure procedure.

NUMBERING OF AIRCRAFT IN A FORMATION

To provide for the Army's future requirements and present operational necessities, it is important that a consistent system of numbering aircraft in any type of formation be established. Aircraft formations are usually illustrated and described as seen from above (plan view). Helicopters are numbered, starting with the leader as No. 1; then, progressively, left to right laterally through each succeeding lateral space area (in the same manner as words and lines on a written page). Helicopters can be changed easily into other related formations and still maintain their original numerical sequence within the new formation.

TWO-HELICOPTER ELEMENT

The two-helicopter section/element is the basic building block for all other formations. It consists of a leader and one wingman. The leader is normally designated as the No. 1 helicopter and the wingman is No. 2. The wingman may fly to the right rear or left rear of the leader, depending on the leader's instructions. A wingman is in right echelon position when flying the right rear, and left echelon position when flying on the left rear. In either echelon position, the correct angular location of the wingman is 45° to the rear of the leader. Distance from the leader should be two times the diameter of the rotor disk with a stepped-up vertical distance of 3 to

10 feet. The wingman's echelon position provides a full view of the lead helicopter from either the pilot's or copilot's seat, and thus permits detection of any change in attitude or flightpath of the element leader. This is a highly maneuverable and flexible formation suitable for free cruise procedure (fig 9-1).

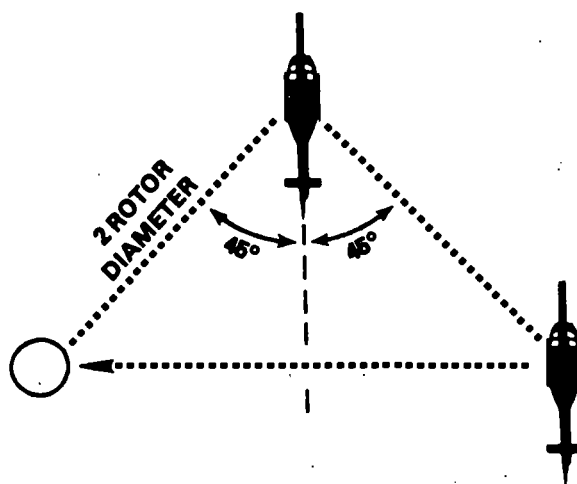


FIGURE 9-1. TWO-HELICOPTER SECTION/
ELEMENT (FREE CRUISE).

Free cruise is a formation procedure that allows the wingman to vary his position in relation to the leader and to avoid the excessive power changes that are necessary to maintain interval during turns. By varying lateral position, the wingman can maintain the interval without changing the power setting. The wingman has the prerogative during a turn to move freely from a 45° position on the outside of the turn to a position nearer the inside of the turn where his speed matches the leader's speed. If the wingman is on the inside of a turn, he can move toward the outside of the turn far enough to match the leader's speed. Interval between aircraft can be maintained in this way without changing the aircraft power setting.

RIGHT OR LEFT ECHELON

The echelon formation may be flown either to the right or left as directed by the leader. This formation is similar to the element, except it contains more than two aircraft. Each succeeding aircraft maintains a 2 rotor disk diameter separation and a 3-foot vertical step-up. Left echelon is illustrated in figure 9-2 and right echelon is shown in figure 9-3.

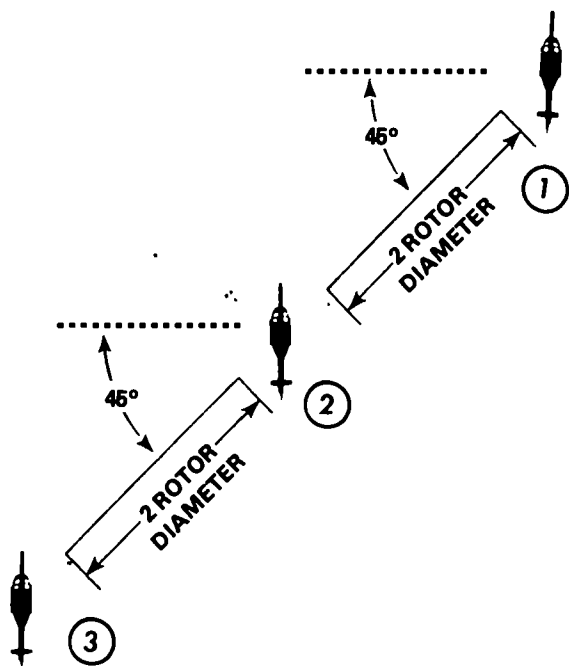


FIGURE 9-2. LEFT ECHELON.

of 3 feet is maintained by the wingmen. The numbering and spacing is shown in figures 9-4 and 9-5.

TRAIL FORMATION

In the trail formation, the No. 2 helicopter takes the position two aircraft lengths directly behind the lead aircraft, with a 3-foot vertical step-up. Each trailing helicopter holds the same relative position

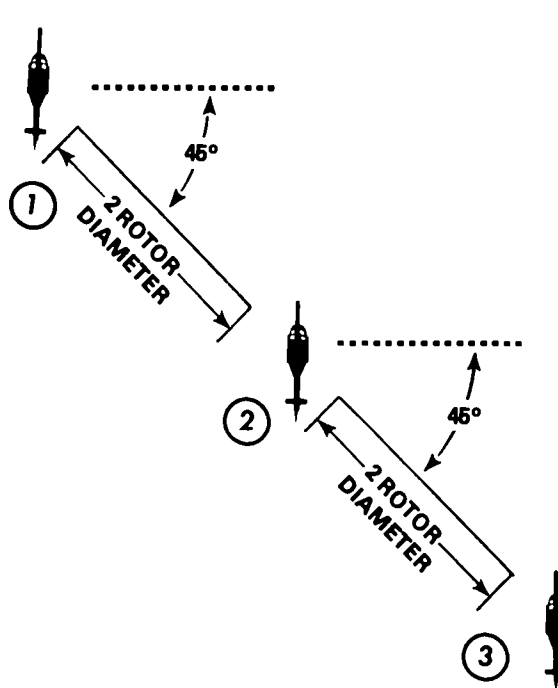


FIGURE 9-3. RIGHT ECHELON.

V-FORMATION

The V-formation consists of a leader, a wingman in left echelon, and a wingman in right echelon. The wingmen hold a position 45° astern of the leader, both right and left and with an interval between helicopters of 2 rotor disk diameters measured between rotor tips. A vertical stepped-up separation

on the aircraft immediately to its front. This formation is not limited to a prescribed number of aircraft. Helicopters are numbered and spaced as shown in figure 9-6.

STAGGERED TRAIL

In the staggered trail formation, each aircraft of the formation holds a position

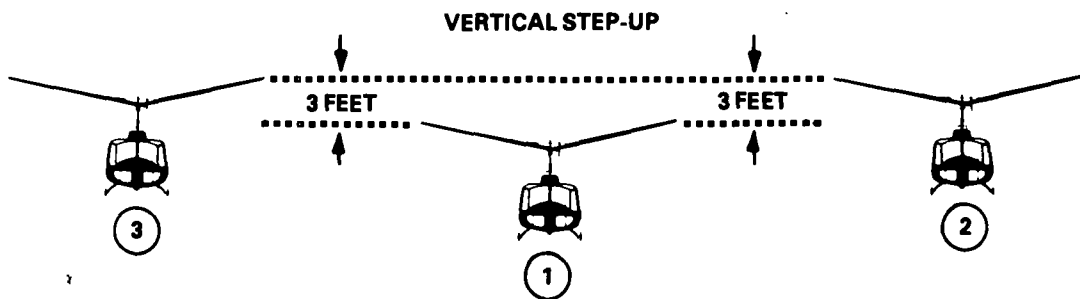


FIGURE 9-4. VERTICAL STEP-UP, V-FORMATION.

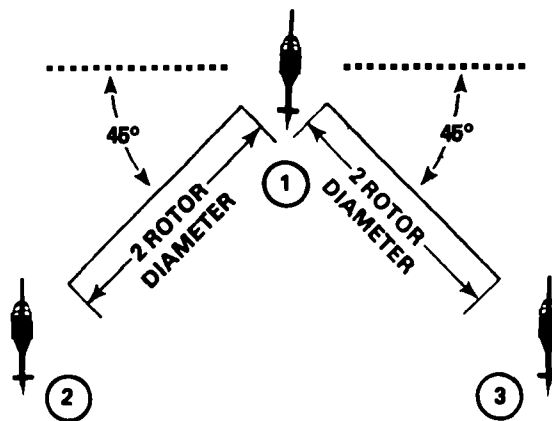


FIGURE 9-5. HORIZONTAL POSITION, V-FORMATION.

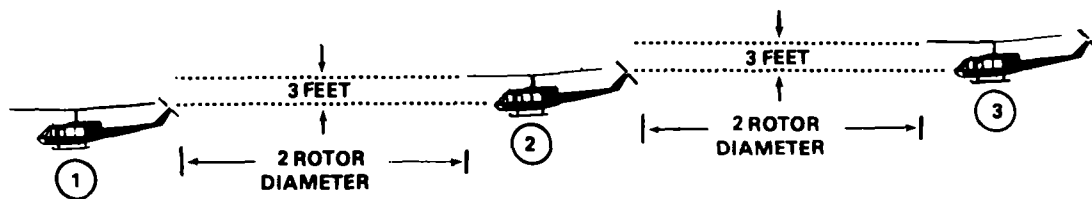
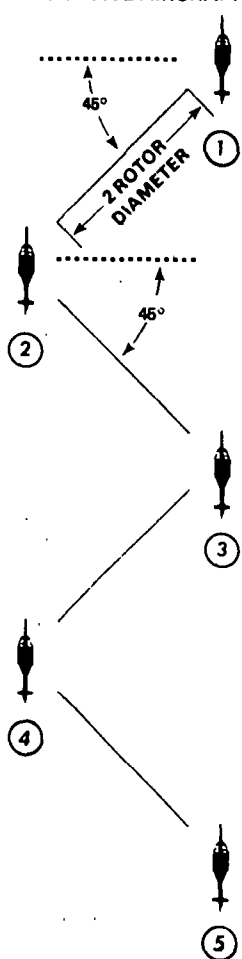


FIGURE 9-6. TRAIL FORMATION.

45° astern, on the aircraft to its front, alternating left and right echelon. Each succeeding aircraft maintains a 3-foot vertical separation on its "lead." This formation is not limited to any prescribed number of aircraft; its size is dictated by the mission requirement. A diagram of positions and numbering is shown in figure 9-7.

STAGGERED TRAIL
LEFT OF FIVE AIRCRAFT



STAGGERED TRAIL
RIGHT OF FIVE AIRCRAFT

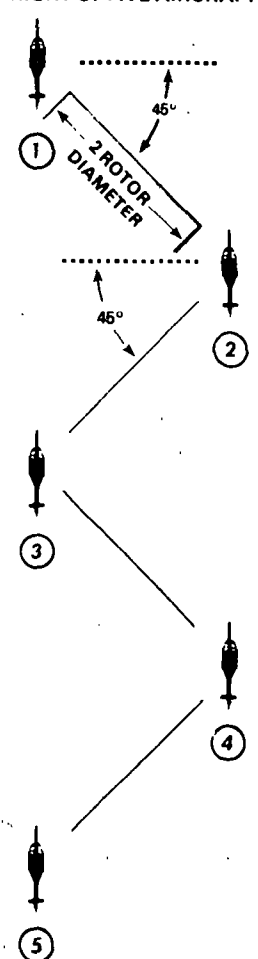


FIGURE 9-7. STAGGERED TRAIL.

DIAMOND FORMATION

In the diamond formation, aircraft numbers 1 through 3 fly the standard "V." The No. 4 aircraft flies a position called the "slot." In the "slot," No. 4 flies directly behind the lead aircraft, and 45° astern of both wingmen, with a 3-foot vertical step-up on No. 3. Helicopters are numbered and spaced as shown in figure 9-8.

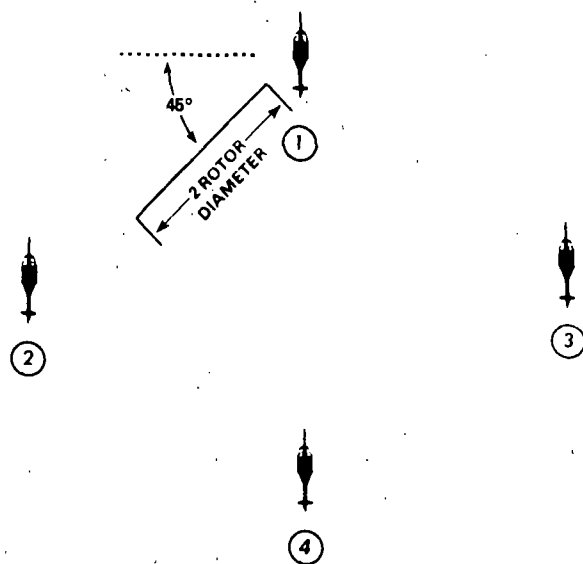


FIGURE 9-8. DIAMOND FORMATION.

TACTICAL HEAVY (LEFT AND RIGHT) FORMATION

The tactical heavy formation is composed of two helicopter sections. In this formation, the leader of the second section flies 45° astern of the flight leader, 3 feet above the flight leader, and opposite the side of the flight leader's wingman. Spacing between sections must be sufficient to permit the wingman or the flight leader to move from or to either echelon

position. Figure 9-9 shows the flight with the second section on the right (heavy right). Figure 9-10 shows the second section on the left (heavy left).

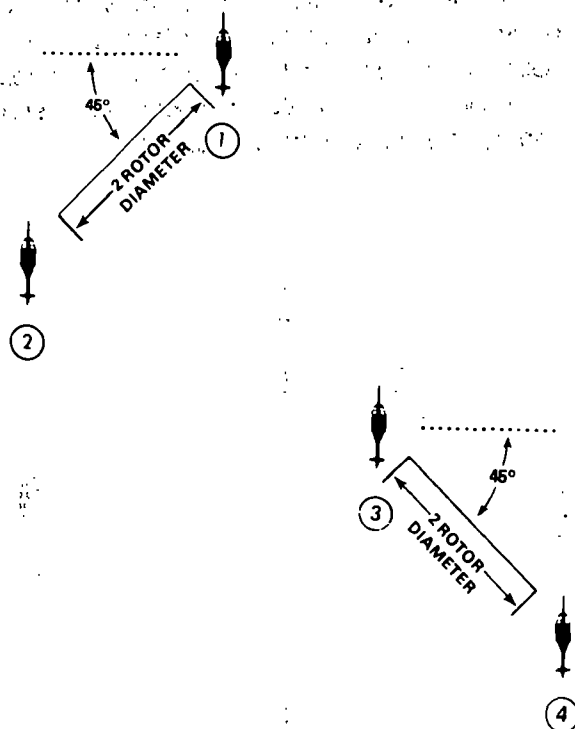


FIGURE 9-9. TACTICAL HEAVY RIGHT FORMATION.

Aerodynamic interference between in-flight helicopters must be anticipated. When two helicopters operate in close proximity, as in trail formation, the interacting patterns of airflow alter the aerodynamics of each helicopter. The leading helicopter may experience an increase in downwash at the tail and a noseup change in pitching movement. The

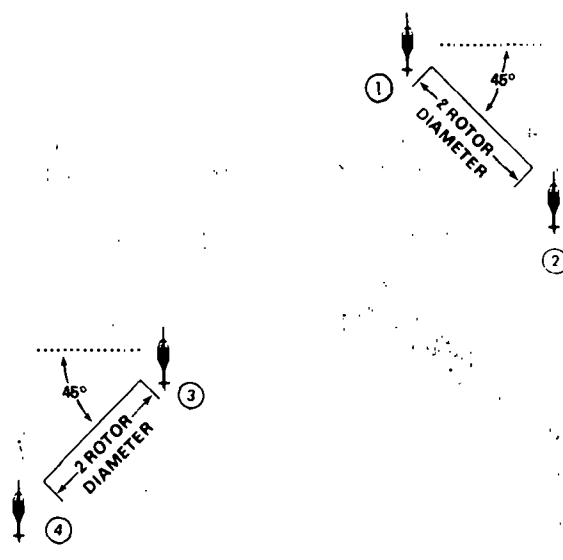


FIGURE 9-10. TACTICAL HEAVY LEFT FORMATION.

BASIC FLIGHT TECHNIQUES

Formation flying is the maneuvering of aircraft (into a flight pattern) in accordance with established tactics, techniques, and procedures, upon the command of a designated leader. It includes the rapid but controlled change from a specific formation suitable for one set of conditions to another formation designed to meet the requirements of an entirely different set of conditions.

trailing helicopter will experience a reduction in downwash at the tail, and nosedown change in pitching movement. Thus a definite possibility of collision exists because of the trim change experienced by each helicopter. In formation flying, the aviator must anticipate this type of interference, particularly when flying in the trail position or when executing a crossover from one position in the formation to another. Care must be taken to anticipate the trim change and to maintain adequate clearance.

Careful planning before conducting formation flights is essential to the safe, efficient control and maneuver of any size formation. Safe and orderly formation flight is the result of extensive training, continuous practice, and a high degree of air discipline. Personnel performing formation flight must do so with an extreme sense of responsibility and with constant vigilance. Although formation flying is not inherently dangerous, any aspect of formation flying can be disastrous if principles are violated.

The distance between helicopters for formations of helicopters can be greatly increased to fit the tactical situation. At higher altitude, helicopters should be positioned far enough apart to prevent a burst of antiaircraft fire from destroying the entire flight. At terrain flight altitudes, aircraft may be spread out to take advantage of the terrain.

An aircraft is maneuvered with reference to only one other aircraft in the formation. The constant vigilance required to detect any change in altitude, airspeed, or heading of the lead aircraft precludes watching other aircraft. If all aircraft guide correctly to their lead, all aircraft have adequate distance and altitude separation for safe operation. In those formations requiring a relative position to more than one aircraft; i.e., staggered trail, or No. 4 position in the diamond formation, the aviator must use peripheral vision to the maximum, while concentrating on his lead aircraft.

FORMATION TURNS

All turns made by the lead helicopter should be constant rate and should not exceed standard rate turn. The reduced degree of bank requires a larger turning radius and must be considered in planning, particularly in the landing pattern. Should it be necessary to exceed standard rate turn, this can best be accomplished by slowly continuing to increase the degree of bank until the desired turn is established. By slowly increasing the bank, the lead ship will allow the wingman time to react. (When flying with inexperienced aviators, it is also a good practice to make a radio call to the flight before making turns, approaches, climbs, landings, etc.) During a turn, the inside wingman will have to decelerate slightly and drop slightly lower than the lead aircraft, while the outside wingman will be required to accelerate and climb slightly to maintain his relative positions in the formation.

CLEARING OBSTRUCTIONS

Regardless of the altitude, it is the responsibility of the formation leader to provide obstruction clearance for all helicopters in the formation. This rule of safety applies during all portions of the flight from takeoff to termination.

CAUTION: While it is the responsibility of the formation leader to provide obstruction clearance for all helicopters in his flight, it is still the responsibility of each individual pilot to maintain his own clearance, if necessary, for obvious safety reasons.

FORMATION TAKEOFF

A formation takeoff is two or more aircraft leaving the ground at the same time and then maintaining a predesignated relative position during the takeoff. Most formation takeoffs are made from the ground. All helicopters should break ground simultaneously at a prearranged signal from the formation leader. During a formation takeoff, the leading elements must accelerate slightly faster than a normal takeoff, which will allow the following elements to gain translational lift. Obstructions permitting, an airspeed-over-altitude takeoff should be made until the flight has established a definite airspeed and rate of climb.

FORMATION LANDING

A formation landing is a landing during which all elements of a formation touch down at the same time while maintaining their relative position within the formation. Where terrain and obstacles permit, landings are made to the ground to avoid hovering turbulence and resulting dust conditions. Every effort must be made to avoid S-turns on final approach, as the airspeed variations required to maintain relative position in the formation are critical at that time, particularly with heavily loaded aircraft. During the formation landing, the leader must insure that sufficient obstacle clearance and landing space is provided for all aircraft in that formation. It is important that the lead element hold straight-and-level flight until the correct approach angle is intercepted, so the rear element can avoid excessively steep or shallow approaches.

FORMATION CHANGES EN ROUTE

☐ *Change from V-formation to echelon.*

The wingman, opposite the side on which the echelon is to form, decreases airspeed until the leader and other wingmen have moved one helicopter length ahead. He then moves laterally to his echelon position (fig 9-11). The reverse of this procedure is used to re-form a "V" from an echelon.

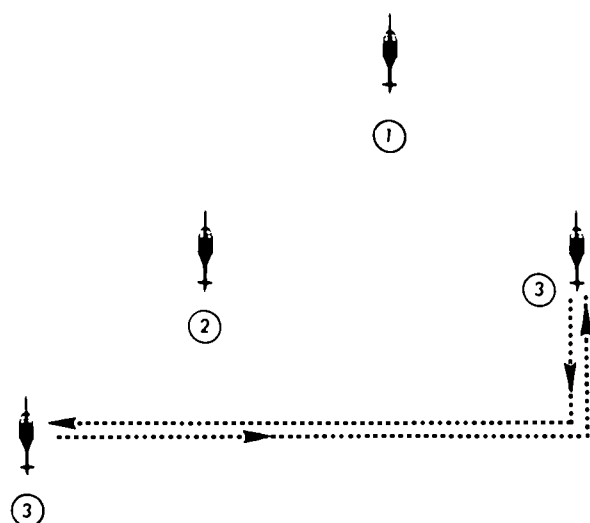


FIGURE 9-11. CHANGE OF FORMATION FROM V-FORMATION TO ECHELON LEFT OR ECHELON LEFT TO "V".

☐ *Change from V-formation to trail.*

The No. 2 and No. 3 wingmen reduce airspeed until the leader has moved ahead of the No. 2 wingman by 3 rotor diameters and ahead of the No. 3 wingman by 6 rotor diameters. The No. 2 wingman then moves laterally to assume a position 2 rotor diameters behind and 3 feet above the leader. No. 3 wingman moves laterally to assume a position 2 rotor diameters behind

No. 2 with 3 feet vertical separation. During this maneuver, only one aircraft is to be moving laterally at one time. No. 2 moves first, then No. 3 (fig 9-12). To change to a V-formation from trail, the reverse of this procedure is followed.

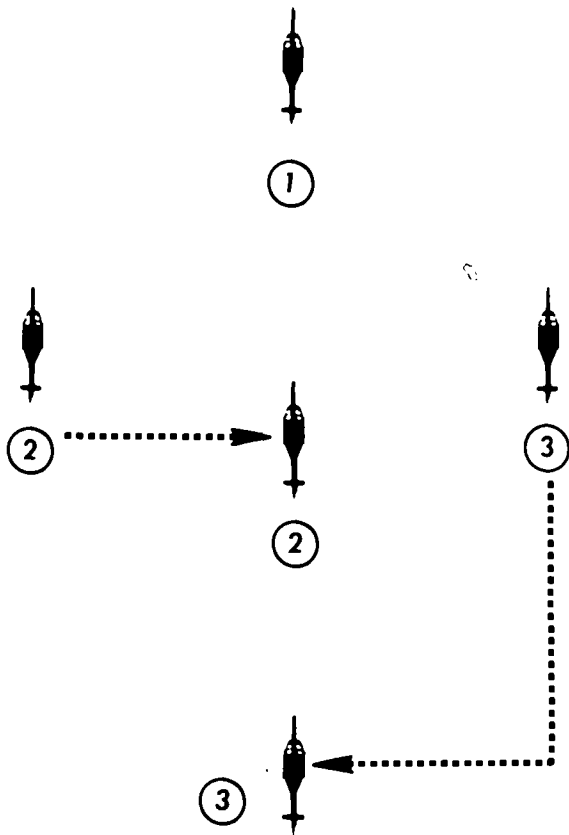


FIGURE 9-12. CHANGE FORMATION FROM V-FORMATION TO TRAIL.

□ *Change from V-formation to a staggered trail (left).* The No. 3 wingman reduces airspeed until wingman No. 2 has moved ahead by 3 aircraft lengths; No. 3 then moves laterally behind No. 1 and at a 45-degree position astern of wingman No. 2 (fig 9-13). The "V" is re-formed by reversing this procedure.

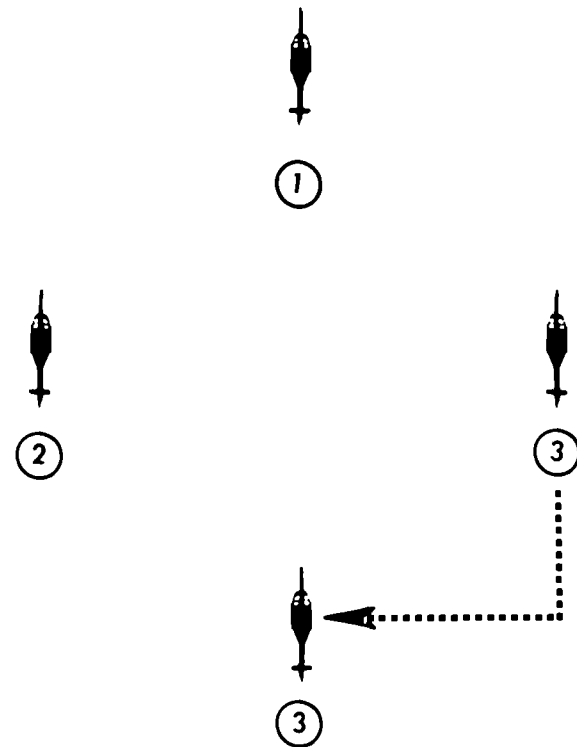


FIGURE 9-13. CHANGE FORMATION FROM V-FORMATION TO STAGGERED TRAIL.

□ *Change from trail to staggered trail (left).* The No. 2 aircraft moves laterally to the left to a position 45° astern of No. 1. No. 3 then closes on No. 1 to a position 45° astern of No. 2 (fig 9-14). To re-form a trail, the reverse is followed. No. 3 must extend his interval before No. 2 can laterally move into the trail position.

□ *Change from tactical heavy left to tactical heavy right.* No. 2 moves to the left, 45° astern of the flight leader (No. 1). No. 3 moves right to a position 45° astern and to the right of the flight leader (No. 1), leaving sufficient space to permit the wingman of the flight leader (No. 2) to move from or to either echelon position.

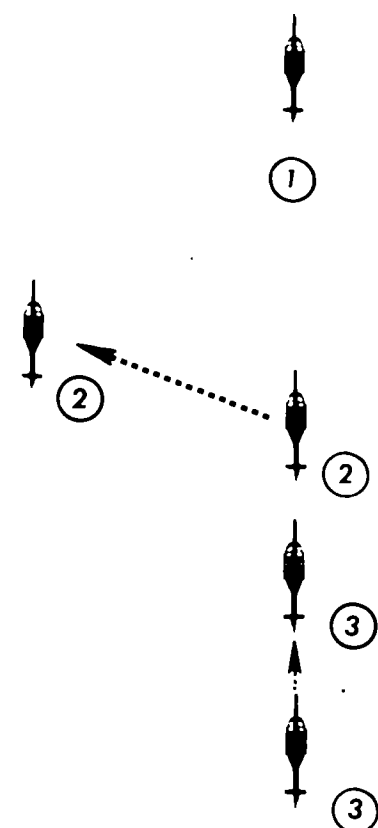


FIGURE 9-14. CHANGE OF FORMATION FROM TRAIL TO STAGGERED TRAIL LEFT.

No. 4 moves with No. 3 and takes a position 45° to the right of No. 3 (fig 9-15). To change from a tactical heavy right to a tactical heavy left, the above procedure would be reversed.

□ *Change from tactical heavy right to staggered trail (left).* Aircraft No. 1 and No. 2 maintain their position. Aircraft No. 3 moves to the left until he is in a position directly behind No. 1 and 45° astern of No. 2. No. 4 moves left to a position directly behind No. 2 and 45° astern of No. 3 (fig 9-16).

□ *Change from tactical heavy left to staggered trail left.* Aircraft No. 2 moves to the left 45° astern of No. 1. Aircraft No. 3 and No. 4 move to the right until the No. 3 is directly behind No. 1 and No. 4 is directly behind No. 2 (fig 9-17).

TACTICAL FORMATION BREAKUP

□ *Breakup of formation into single aircraft.* This maneuver may be used when an LZ is big enough for only one aircraft at a time or for any other reason that it may be necessary to break the formation initially (fig 9-18). When formed in echelon formation, the leader designates the interval (normally 10 seconds) between breaks. On the command "Execute," the leader turns 90° away from his wingman to be followed 10 seconds later by No. 2, 20 seconds later by No. 3, etc. (fig 9-18). When this maneuver is used for landing in a single-ship LZ, the formation ideally approaches the LZ on the landing heading and starts the breakup over the LZ as shown in figure 9-19.

□ *Breakup of formation into two aircraft elements.* The flight leader directs a staggered trail formation initially for this maneuver. After the formation has closed into a staggered trail, the flight leader will announce the time interval between elements, and receive an acknowledgment. On the command "Execute," the first two aircraft will continue on course; and if load and flight conditions permit, will increase airspeed by 10 knots. The remainder of the aircraft will slow by pairs until desired separation is attained. An exception to the above procedure must be used with large formations to avoid stacking up of the last

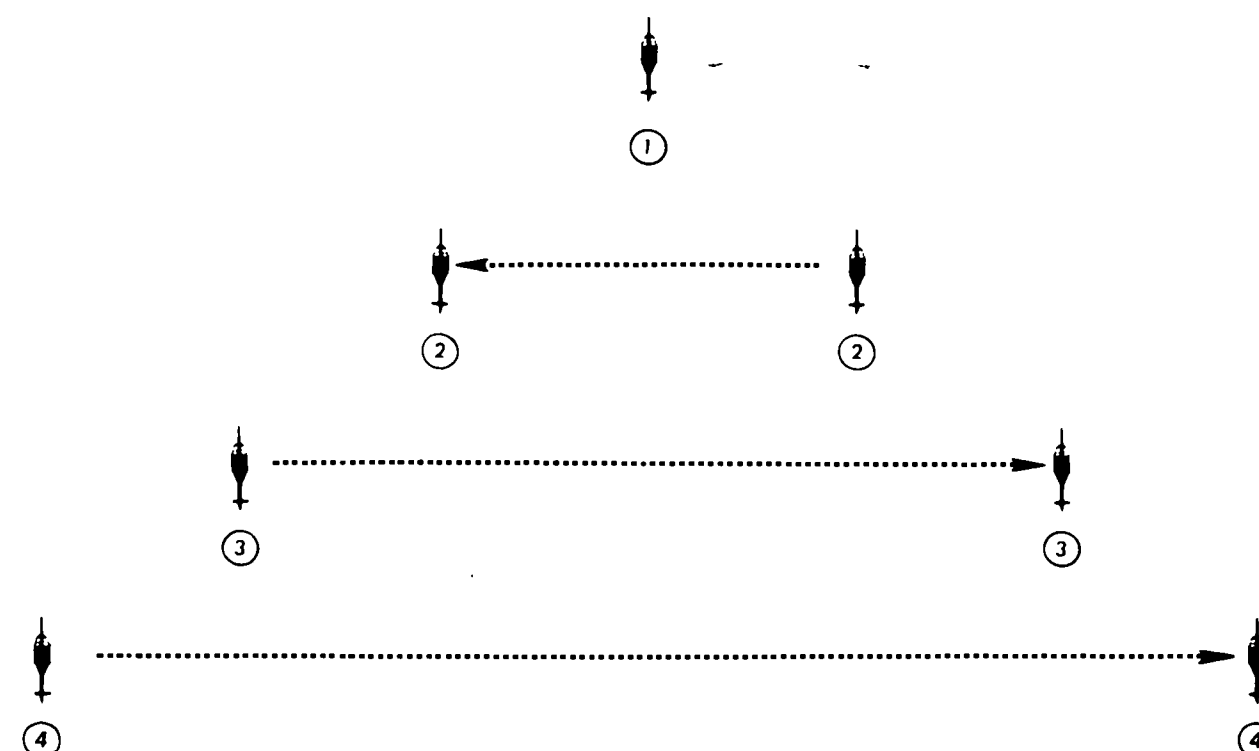


FIGURE 9-15. CHANGE OF FORMATION FROM HEAVY LEFT TO HEAVY RIGHT.

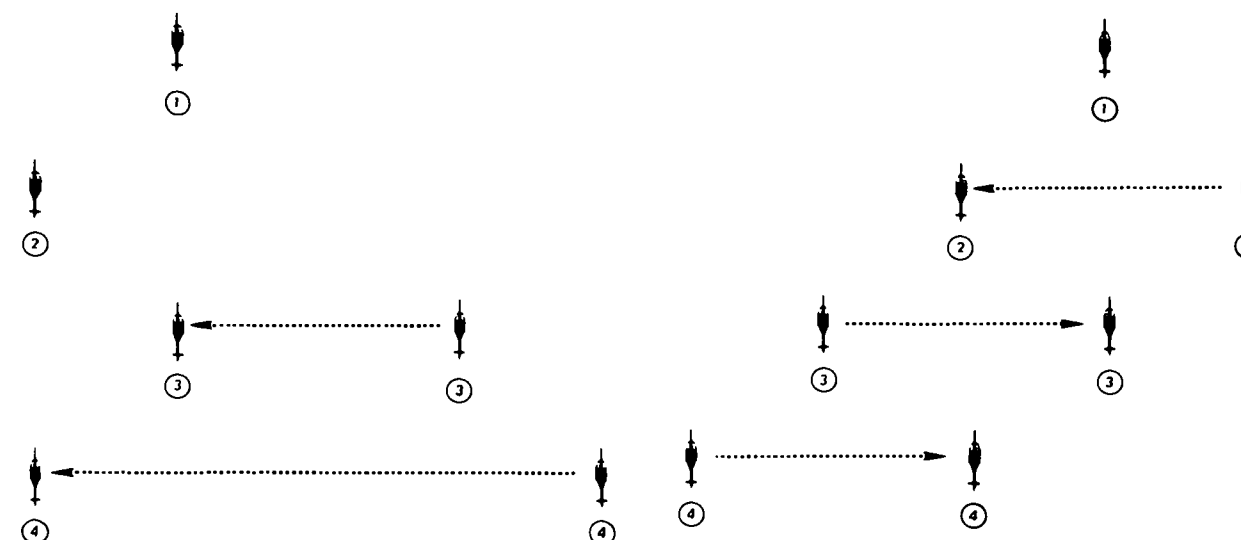


FIGURE 9-16. CHANGE OF FORMATION FROM HEAVY RIGHT TO STAGGERED TRAIL LEFT.

FIGURE 9-17. CHANGE OF FORMATION FROM HEAVY LEFT TO STAGGERED TRAIL LEFT.

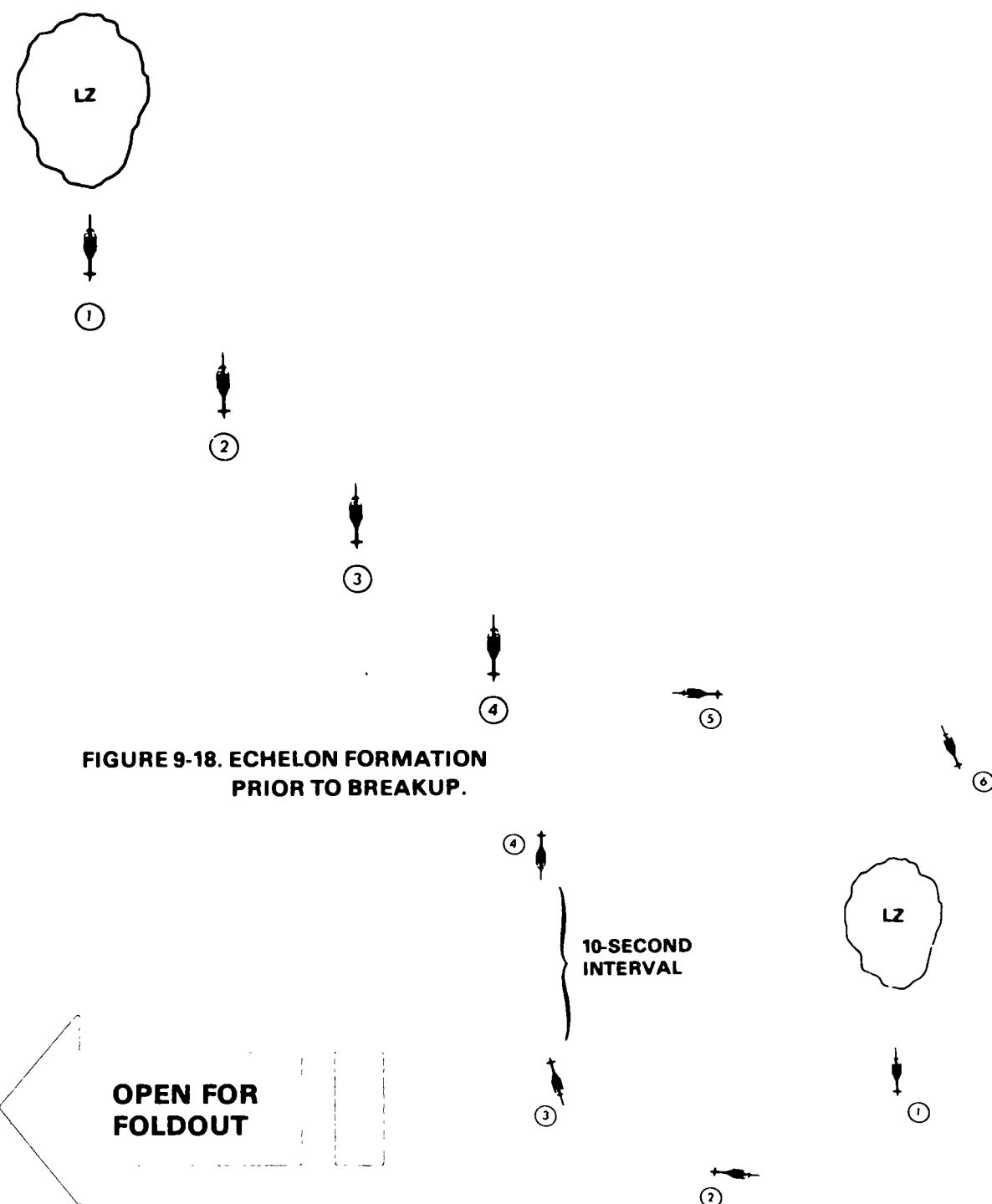


FIGURE 9-18. ECHELON FORMATION PRIOR TO BREAKUP.

FIGURE 9-19. LEFT BREAK WITH 10-SECOND INTERVAL FOR LANDING.

aircraft. This exception is at the command "Execute," the lead aircraft will enter a standard rate (right or left, as designated), 180-degree turn. Each subsequent two-aircraft element will fly the designated separation interval and then enter a standard rate, 180-degree turn in the same direction as the lead element. As the turn is completed, the flight has proper separation and can continue in the desired direction.

RENDEZVOUS AND JOINUP

The flight leader will approach the rendezvous point at the preplanned time and altitude. Upon reaching the rendezvous point, he will enter an orbit in the preplanned direction using a standard rate turn and an airspeed 60/70 knots. Joining members of the flight will approach the lead aircraft by crossing his orbit at 70 to 90 knots and at the same altitude. As final joinup is completed, airspeed will be reduced and heading varied so as to close into a trail position on the lead aircraft. A safe rate of closure is essential during joinup.

NIGHT FORMATION FLYING

Procedures for night formation flight are basically the same as day formation flight, the primary difference being aircraft spacing. During night flight, the interval between helicopters is *increased* to 3 to 5 rotor disk diameters. During night flight, pilot depth perception is greatly *reduced*. For this reason, changes in formation must be kept to the minimum.

Aviators executing a joinup, formation change, or adjusting position must take

care that their rate of closure is slow enough to be stopped quickly, and that they do not overrun the helicopter immediately ahead. The silhouette of a helicopter cannot be seen except at a close distance; the best point of reference is the position lights. Rotating beacons should not be used during night formation flight.

Another problem encountered during night formation flight is *fixation*. Fixation occurs when the aviator looks or stares too long or too hard at a point. When experiencing fixation, the pilot is unaware of the movement of his aircraft or the aircraft he is flying formation on. To avoid this fixation, the aviator must look around, moving his eyes from one position to another.

COMMUNICATIONS PROCEDURES

A communications check on the command/operation net is required prior to departure on a formation flight. Current regulations require that all aircraft of a formation have operational radio communications and that communications are established between all aircraft of the formation.

Prior to initiating an enroute formation change, rendezvous, and joinup or formation breakup, positive communications must be established with all elements of the flight. An acknowledgment of the transmission directing the maneuver is required to insure complete understanding of the maneuver and to avoid misinterpretation of an aircraft's movement. These maneuvers should not be attempted if communications are lost.

All formation changes and frequency changes are directed by the formation leader, using a preparatory command and a command of execution.

Communication examples:

☐ *Commo check:* "Rampart flight, this is Rampart 31; FM commo check; over."

Reply: "Rampart 32, I hear you loud and clear." "Rampart 33, I hear you loud and clear," etc., in numerical sequence.

Rampart 31, "Roger, I have all four aircraft loud and clear."

☐ *Forming of flight:* "Rampart 30 flight, this is Rampart 31, tail number 54763; form on me in tactical heavy left; acknowledge."

Reply: "Rampart 32, Roger." "Rampart 33, Roger," etc.

"Rampart 30, this is Rampart 31; execute formation lineup."

Reply: "Rampart lead, this is Rampart 34; your flight is formed in tactical heavy left."

☐ *Formation takeoff:* "Rampart 30 flight, this is Rampart 31; pitch-pull in 10 seconds."

"Rampart 31, this is Rampart 34; your flight is off."

"This is Rampart 31, Roger."

Reply after flight joined: "Rampart 31, this is Rampart 34; your flight is joined tactical heavy right."

"Rampart 34, this is Rampart 31; Roger, going 90."

☐ *Frequency change:* "Rampart 30 flight, this is Rampart 31; the next UHF frequency will be command UHF; acknowledge."

Reply: "Rampart 32, Roger." "Rampart 33, Roger," etc.

"Rampart 30, this is Rampart 31; execute command UHF."

☐ *Formation change in flight:* "Rampart 30 flight, this is Rampart 31; the next formation will be echelon right; acknowledge."

Reply: "Rampart 32, Roger." "Rampart 33, Roger," etc.

"Rampart 30 flight, this is Rampart 31; execute echelon right."

Reply after proper formation change: "Rampart 31, this is Rampart 34; your formation is joined echelon right."

☐ *Formation break:* "Rampart 30 flight, this is Rampart 31; prepare to break left at 5-second intervals, (give rendezvous instructions) call the break; acknowledge."

Reply: "Rampart 32, Roger." "Rampart 33, Roger," etc.

"Rampart 30 flight, this is Rampart 31; breaking now."

Five seconds later: "Rampart 32; breaking this time."

Five seconds later: "Rampart 33; breaking this time."

When all aircraft have landed: "Rampart 31, this is Rampart 34; your flight is down with four aircraft."

"Rampart 31; Roger."

FORMATION BREAKUP PROCEDURES WHEN VISUAL CONTACT WITH OTHER AIRCRAFT IS LOST

Helicopter flight crews must be trained to cope with marginal weather conditions that may be encountered during formation flight. If visual contact with other aircraft in the formation is lost, a standard formation breakup procedure should be used. This procedure should be covered in detail during the mission briefing. Radio communication must be maintained with the flight leader to facilitate breakup. All turns, climbs, and descents should be done at a predetermined standard rate. The following procedures are only guidelines for units to further develop their own procedures, based on the mission, terrain, and enemy situation.

ENTERING IMC THAT PERMITS VISUAL CONTACT

When weather conditions permit the helicopters in formation to remain in visual contact with each other, one of the following procedures may be used:

☐ The formation leader may decide to continue and complete the mission, pro-

vided each aircrew in the formation is instrument qualified.

☐ The formation leader may elect to perform a 180-degree formation turn out of the IMC condition.

ENTERING IMC THAT DESTROYS VISUAL CONTACT

When weather conditions are entered which instantly destroy all visual contact between helicopters in the formation, each aircrew (as simultaneously as possible) must immediately initiate the breakup maneuver designed for their respective position (fig 9-20).

BREAKUP PROCEDURES

The duties of the formation leader do not require him to observe the other helicopters with as much consistency as they must observe one another. Therefore, the formation leader depends on the aircrews in the flight (usually the No. 3 helicopter) to announce over the radio: "Visual contact impossible...executing breakup procedures." Upon receipt of this statement, the formation breaks up according to a prearranged plan. For a staggered trail formation, the following procedure could be used (fig 9-20).

☐ The flight leader continues straight ahead and reports his magnetic heading and altitude.

☐ The No. 2 aircraft executes a 30-degree turn away from the flight leader and climbs 100 feet.

□ The No. 3 aircraft executes a 30-degree climbing turn away from the No. 2 aircraft and climbs 200 feet.

□ The No. 4 aircraft executes a 60-degree climbing turn away from the No. 3 aircraft and climbs 300 feet. The No. 5 aircraft executes a 60-degree climbing turn away from the No. 4 aircraft and climbs 400 feet.

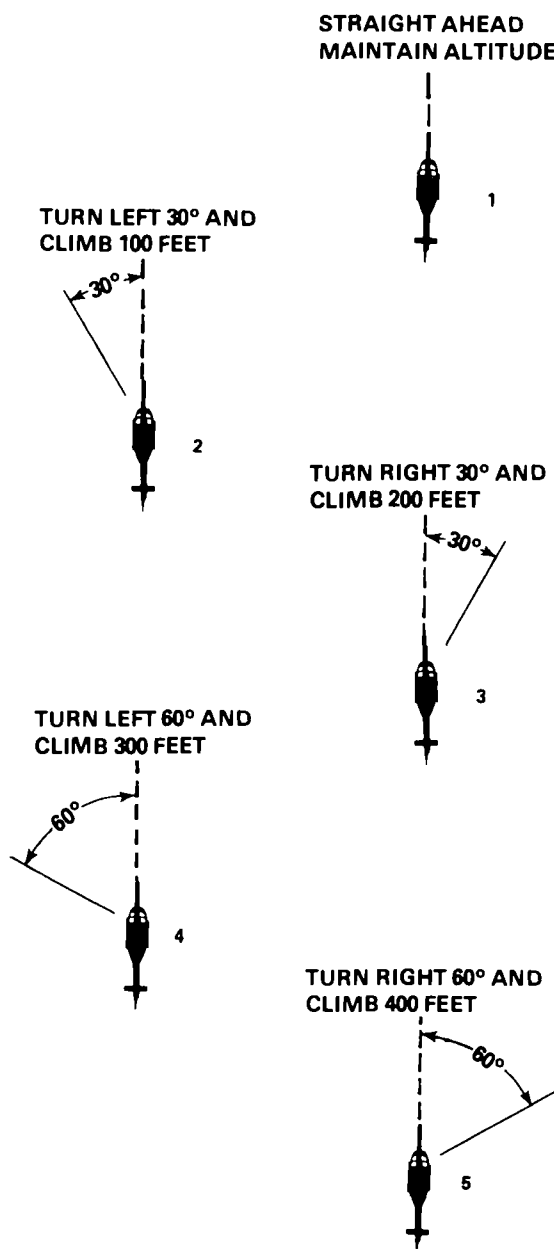


FIGURE 9-20. FORMATION BREAKUP PROCEDURE WHEN VISUAL CONTACT CANNOT BE MAINTAINED UPON ENTERING IMC.

RECOVERY PROCEDURES

When the formation has been dispersed, as described above, the flight leader should proceed according to the local VERTICAL HELICOPTER IFR RECOVERY PROCEDURES. The leader should release aircraft to air traffic control in priority, based on fuel remaining or other variables. If a VERTICAL HELICOPTER IFR RECOVERY PROCEDURE has not been prearranged, the flight leader should contact the appropriate air traffic control facility and arrange for an instrument approach for aircraft in the appropriate order. When ATC facilities are not available, the flight leader should proceed as follows to regain visual contact.

□ After all helicopters have completed the initial breakaway turn and climbed to their assigned altitude, they fly a straight course for 30 seconds. The flight leader then commands over the radio, "No. 4 and No. 5 helicopters, complete a 180-degree turn." The No. 4 and No. 5 helicopters acknowledge the communication and continue their turn until their heading is 180 degrees from the original heading of the formation. After ordering the No. 4 and No. 5 helicopters to complete the 180-degree turn, the flight leader waits 10 seconds and instructs the No. 2 and No. 3 helicopters to complete their 180-degree turn. Ten seconds later, the flight leader starts his own 180-degree turn.

☐ When helicopter No. 5 has reversed direction, it should maintain heading, decelerate to minimum safe forward speed, and begin a slow descent until visual contact is reestablished. The pilot should concentrate on the aircraft instruments, and the copilot should look outside the aircraft for visual contact with the terrain. When aircraft No. 5 reports reaching VMC, the helicopter at the next lowest altitude can start a descent to VMC. This sequence is continued until all helicopters report to the leader that they are VMC, giving their location if known. The flight leader can then proceed to rendezvous and join up the formation.

☐ This procedure for formation breakup will provide both altitude and lateral separation of all aircraft. However, if all aviators cannot, for example, maintain altitude within plus or minus 100 feet, the lateral separation as provided is still sufficient to prevent midair collisions.

☐ Since all helicopters may not lose visual contact at the same time, the aviator that first loses visual contact should identify himself to the flight leader and announce that he is executing the breakup procedure (for his position in the formation, as set forth above).

CHAPTER 10

PRECAUTIONARY MEASURES AND CRITICAL CONDITIONS

GENERAL PRECAUTIONARY RULES

Because of its unique flight characteristics, a helicopter is capable of many missions no other aircraft can perform. A rotary-wing aviator must, however, realize the hazards involved in helicopter flight. He should know how to apply precautions which might save the helicopter or even his life. He should:

- ☐ Check weight and balance prior to flying.

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- ☐ Assure that any object placed in the cockpit of a helicopter is well secured to prevent fouling of the controls.

- ☐ Caution approaching or departing passengers of main rotor/tail rotor dangers at all times during ground operations. Personnel carrying long objects such as pipe, wood, tripods, etc., should not be allowed to approach a helicopter whose rotor blades are turning, because of the danger of these objects striking the rotor blades.

- ☐ Ground taxi slowly.

- ☐ Maintain normal operating rotor RPM during all flight conditions.

- ☐ Hover for a moment before beginning forward flight.

- ☐ Avoid high hovering and become familiar with the height velocity diagram in the operator's handbook.

- ☐ Use caution when hovering on the lee side of buildings or obstructions.

- ☐ Avoid hovering in dusty areas or debris-covered areas.

- ☐ Develop and use a constant cross-check for engine, transmission, and systems instruments.

☐ Perform only maneuvers authorized in the Operator's Manual.

☐ When flying in rough, gusty air, maintain penetration airspeed recommended in the aircraft Operator's Manual.

☐ Always clear the area overhead, ahead, to each side, and below, before entering practice autorotations.

☐ Avoid engine and rotor overspeeding beyond the Operator's Manual recommendations.

ROTOR RPM

OPERATING LIMITS

Limits of rotor RPM vary with each type of helicopter. In general:

☐ *Low rotor RPM limits* are determined to prevent high blade coning and excessive flapping angles. In engine failure autorotation, rotor RPM decay below certain levels will not respond to corrective measures. Below safe normal rotor RPM limits, there is:

⊙ Greater danger of mast bumping or of the rotor blades striking the fuselage.

⊙ Possible sluggish control response.

☐ *High rotor RPM limits* are established to prevent possible structural failure and damage to rotating assemblies caused by too high centrifugal loads developed by the rotor blades.

TURBINE ENGINE OPERATING LIMITATIONS

The gas turbine is a most reliable and trouble-free engine. It operates in a continuous cycle which is conducive to long engine life. The engine is designed to operate at high power outputs and operates most efficiently at high powers. However, the operating limitations of the engine must be observed meticulously if the engine is to exhibit the long, trouble-free life which is expected of it.

☐ *Exhaust gas temperature* provides one of the most important limitations upon the operation of the gas turbine. The exhaust gas temperature may be taken at any of a number of positions following the final turbine stage in the engine. It is for this reason that it is difficult to compare temperatures between models. When the turbine is designed, an instrumented engine is used to determine the proper position to take the exhaust gas temperature so the most reliable indication of turbine temperature is obtained. It is the *turbine temperature* which is of importance and is the true limitation. It is the turbine which puts the lid on the whole engine with its limiting temperature, caused by the material of which it is constructed and the stresses on the material caused by the aerodynamic and centrifugal loads. The exhaust gas temperature is not a direct reading of the limitation, but an indirect reading. However, the limitations so indicated must be carefully obeyed.

☐ In conjunction with the exhaust gas temperature, *an RPM limitation* will be established on the engine. The RPM limitation is primarily a stress limitation

and is caused by the maximum stress which the turbine can withstand at the operating temperatures. It is for this reason that the temperature and RPM limitations go together and are listed in the pilot's handbook as a dual limitation.

□ Of course, an overspeed engine condition breeds overtemperature. In this relation they tend to go together. However, an overtemperature may occur without overspeed, such as during an improper start. The overtemperature and overspeed limitations which are listed together in the pilot's handbook usually provide *starting temperature* limitations.

□ The turbine is under two distinct types of *structural stress*. It is undergoing *creep*, that elastic phenomenon caused by stress at high temperatures. It is also subject to *fatigue* due to the high frequency aerodynamic and structural vibrations which occur in the engine. Both of these effects are cumulative.

• If the temperature is elevated for a period of time, the rate of *creep* will increase. If simultaneously the stress is increased, the rate of creep will increase by an order of magnitude. Therefore, while damage may not be visible to the eye following an overstress and/or overtemperature, there will be some shortening of engine life. It is therefore imperative that there be some recording of the limitation which was exceeded, so that a judgment may be made as to when the engine must be inspected for creep damage.

• A similar situation exists with respect to *fatigue* damage. An overspeed

condition accompanied by overtemperature will increase the fatigue environment to the point that significant increases in the fatigue damage may occur.

• A gross overstress or overtemperature of the turbine section will produce damage that is apparent to the eye. However, *creep* and *fatigue* damage accumulated through periods of small overstress and overtemperature will cause damage which will shorten the service life and may cause failure to occur prior to the normal removal and inspection dates.

The magnitude of the overstress produced by the overspeed is not proportional to the overspeed, but increases somewhat more rapidly than the overspeed. Therefore a 5-percent overspeed in RPM will produce approximately a 10-percent overstress. This large increase in stress with RPM not only shortens the life of the turbine, but has adverse effects on the compressor and other components of the turbine which may be sensitive to vibration and fatigue.

It is well, therefore, for the pilot to be aware of the various combinations of RPM and temperatures which are allowable for certain periods of time. These limitations may be listed in blocks, some of which may be allowed, some of which must be reported, some of which require engine removal and inspection, and some of which require an engine change. Although it is embarrassing for the pilot to make such a report, particularly when no damage is visible, it is most important that he do so if the proper safety measures are to be taken.

EXTREME ATTITUDES AND OVERCONTROLLING

Extreme attitudes and overcontrolling should be avoided. See approved maneuvers in the Operator's Manual.

☐ A helicopter should not be loaded so as to cause an extreme tail-low attitude.

☐ Heavy loading forward of the center of gravity should be avoided. Limited aft travel of the cyclic stick results, endangering controllability.

☐ Extreme nose-low attitude should be avoided when executing a takeoff. Such an attitude may require more power than the engine can deliver and will allow the helicopter to settle to the ground in an unsafe landing attitude. In the event of power loss on takeoff, a comparatively level attitude can assure a safe touchdown.

☐ Rearward cyclic control should never be abruptly applied. The violent backward-pitching action of the rotor disk may cause the main rotor blades to flex downward into the airframe.

☐ Large or unnecessary movements of the cyclic control should be avoided while at a hover. Such movements of the cyclic control can cause sufficient loss of lift, under certain conditions, to make the helicopter inadvertently settle to the ground.

☐ When executing 360° hovering turns in winds of 10 knots or more, the tail of the

helicopter will rise when the downwind portion of the turn is reached. When this happens, if the rear cyclic control limit is exceeded, the helicopter will accelerate forward; and a landing must be made immediately.

☐ Avoid abrupt antitorque pedal movements while at a hover. Turns in excess of 360° in 15 seconds will place stress on the tail boom that may result in a failure.

HIGH SPEED AUTOROTATIONS

When entering autorotations in most helicopters at high airspeeds, the nose pitches upward after collective pitch is lowered. With an aft center of gravity, this condition can become critical by having insufficient forward cyclic control to effect a recovery. (A large amount of forward cyclic control is used even in recovery of a well-balanced helicopter.) When the nose pitches up, application of forward cyclic may cause mast bumping. To avoid this unsafe condition, a nose-high attitude should be maintained. This deceleration attitude will slow the helicopter. Depending on the airspeed of the helicopter, additional aft cyclic may be required. Upon decelerating to the desired autorotational airspeed, the attitude of the helicopter is readjusted to maintain normal descent airspeed. Upon entering the deceleration attitude, the collective is lowered to maintain normal operating RPM. At high airspeeds, it may be necessary to maintain pitch in the blades to control the RPM. As the helicopter decelerates to the best glide airspeed, the pitch should be in the full down position.

OPERATIONS WITH REDUCED VISIBILITY AND LOW CEILING CONDITIONS

By reducing speed to the limits of visibility so that a rapid deceleration may be executed if an obstacle appears in the flightpath, flight can be continued with low ceilings and visibility. The aviator must, however, be aware of the hazards of downwind flight at low altitudes under these conditions. Whenever further flight appears hazardous, an aviator can execute a landing (vertical if necessary) and remain on the ground until further flight is possible.

OPERATIONS IN PRECIPITATION

☐ *Rain and Snow.* Light rain and snow have comparatively little effect on the helicopter, and flight can usually be continued. However, heavy rain and snow have an abrasive effect on the rotor blades; therefore, flight should be discontinued during heavy rain or snow.

☐ *Hail.* Hail, the most serious type of precipitation from an abrasive standpoint, should be avoided by skirting weather areas where hail is likely. If hail is encountered during flight, a landing should be made as soon as possible and the helicopter inspected for damage.

☐ *Freezing Rain.* Freezing rain is the most dangerous type of precipitation encountered. Ice quickly forms on the windshield, and complete loss of vision

through the windshield can be expected as the ice thickens. By looking to the side or jettisoning the door, the aviator may retain enough visibility to effect a safe landing.

WARNING: An aviator should never stare through a windshield on which ice is forming; a loss of sense of direction and movement result.

Formation of ice on the rotor blades causes an unbalanced condition and a disruption of streamlined airflow. The resultant loss of airfoil symmetry may cause the center of pressure to move as the angle of attack changes, resulting in reduced control effect and unusual feedback of undesirable control pressures. Uneven ice formation causes unbalanced rotor blades which produce excessive vibration of the entire helicopter.

CAUTION: The aviator must not attempt to throw ice off the blades by sudden rotor acceleration, or by rapid control movements. At best, only a small portion of the blade ice could be thrown off, probably incurring additional rotor unbalance.

Under weather conditions in which temperature and dewpoint are close together and near freezing, ice may build up rapidly on a rotor system operating at low RPM (as in a parked helicopter with idling engine). When these conditions are suspected, the aviator should stop the engine and inspect the rotor blades before attempting a takeoff.

Additional indications of icing include:

- Ice forming on the windshield.
- Loss of RPM. As the ice builds up, drag increases, causing a loss in RPM. The aviator must repeatedly add power and/or reduce pitch to maintain RPM.
- Mushy cyclic control.
- Excessive vibration.

CAUTION: When this condition occurs, it may not be possible to maintain an autorotational speed above the lower limit.

AIR DENSITY AND PRESSURE ALTITUDE

Low air density at high pressure altitude reduces helicopter efficiency during hot weather operation. When air is subjected to heat, it expands and becomes thinner (fewer air particles per cubic foot). Since lift is obtained from air particles and since, under thinner air conditions, there are fewer air particles per cubic foot, it is necessary to operate the rotor blades at a higher angle of attack. This condition requires more power and reduces the load-carrying capability of the helicopter. Normal ascent, hovering, and descent may become impossible; running takeoffs and landings may become necessary as operation becomes more critical.

FLIGHT TECHNIQUE IN HOT WEATHER

When flying in hot weather, the aviator should:

☐ Make full use of wind and translational lift.

☐ Hover as low as possible and no longer than necessary.

☐ Maintain maximum allowable engine RPM.

☐ Accelerate very slowly into forward flight.

☐ Employ running takeoffs and landings when necessary.

☐ Use caution in maximum performance takeoffs and steep approaches. Complete a power check prior to takeoff.

☐ Avoid high rates of descent in all approaches.

OTHER OPERATIONS

☐ *High-Altitude Operation.* Although civil and military tests have proved that the helicopter is capable of performing successfully at high altitudes, they have also proved that high-altitude operation usually is marginal and demands a high degree of aviator proficiency. Aviators assigned high-altitude missions must be thoroughly familiar with the factors affecting helicopter performance and the flight techniques involved. To operate successfully at high altitudes, the aviator must first determine that the factors affecting helicopter performance do not exceed the operating limits of the machine. The three major factors to understand are:

① Air density.

- An increase in altitude causes a decrease in air density.

- An increase in temperature causes a decrease in air density.

- An increase in humidity causes a decrease in air density.

② Wind.

- If there is sufficient wind velocity to afford translational lift while hovering, helicopter performance is improved considerably.

- Translational lift, present with any forward speed or headwind, has an insignificant effect until speeds of approximately 15 to 20 knots are obtained.

③ Load.

- Load is a variable factor and must be considered carefully by the aviator. Smaller amounts of fuel may be carried to improve performance or increase useful load; however, this necessitates a sacrifice in range.

- Under conditions of high density altitude, additional engine power is required to compensate for the thin air. If the maximum gross weight of the helicopter exceeds the limits of available engine power, a reduction in load may be necessary.

- Due to changes of density altitude and wind velocity during the day, the weight-carrying capability of a particular helicopter may vary many times during a single day.

- Established service ceilings for each helicopter must be considered in computing maximum load for safe operations.

□ *Effect of Altitude on Instrument Readings.* The thinner air of higher altitudes causes the airspeed indicator to read low. True airspeed may be roughly computed by adding 2 percent to the indicated airspeed for each 1,000 feet of altitude above sea level. For example, an indicated airspeed of 100 knots at 10,000 feet will be a true airspeed of 120 knots. A more accurate computation may be made by using the dead-reckoning navigational computer.

□ *Effect of Altitude on Engine Power.* Engine power is reduced as air density decreases. Figure 10-1 shows a typical plot of turbine engine power versus density altitude. See the appropriate aircraft Operator's Manual for specific performance charts for each aircraft.

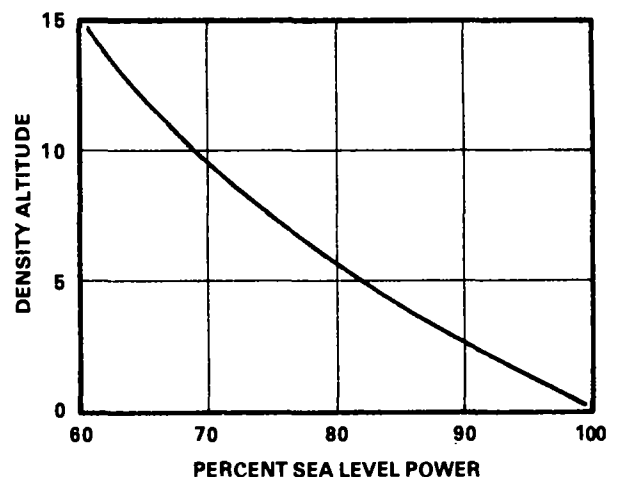


FIGURE 10-1. TURBINE ENGINE POWER OUTPUT VERSUS DENSITY ALTITUDE

□ *High Altitude Flight Techniques.* Of the three major factors limiting helicopter performance at high altitude, only load may be controlled by the aviator. At the expense of range, smaller amounts of fuel may be carried to improve performance or increase useful load. The weight and balance aircraft records should be consulted to insure efficient loading. Where practical, running landings and takeoffs could be used. Favorable wind conditions are helpful, with landings and takeoffs directly into the wind if possible. In mountainous terrain, flight should be on the upwind side of slopes to take advantage of updrafts. When landing on ridges, the safest approach is usually made lengthwise of the ridge, flying near the upwind edge to avoid possible downdrafts and to be in position to autorotate down the upwind side of the slope in case of forced landing. Using the updraft in this manner results in lower rate of descent, improved glide ratio, and greater choice of a landing area.

□ *Operations Over Tall Grass.* Tall grass disrupts airflow and disturbs normal downwash angle with two results: the induced rotor drag is increased and the rotor airflow pattern is changed. More power will be required to hover, and takeoff may be very difficult.

□ *Operations Over Water.* Altitude is difficult to determine when operating over water with a smooth or glassy surface. Thus, caution must be exercised to prevent the helicopter from inadvertently striking the water or from terminating approach at a high hover. This problem does not exist over rough water, but a very rough water surface may disperse the "ground" effect and thereby require more power to hover.

Movements of the water surface, wind ripples, waves, current flow, or even agitation by the helicopter's own rotorwash tend to give the aviator a false feeling of helicopter movement. The aviator should avoid staring at the water; he can remain oriented by frequent reference to objects in the water such as ships, buoys, floating debris, or objects on a distant shoreline.

MAST BUMPING IN THE SEMIRIGID ROTOR SYSTEM

Inappropriate pilot response to low-G maneuvers, engine failure, and some types of tail rotor failure, can lead to mast bumping and possible rotor mast failure. Mast bumping is the result of excessive rotor flapping. Each rotor system design has a maximum flapping angle at which a static stop prevents further flapping. If flapping exceeds the design value the static stop contacts the mast. It is the violent contact between the static stop and the mast during flight that causes mast damage or separation. This contact must be avoided at all costs.

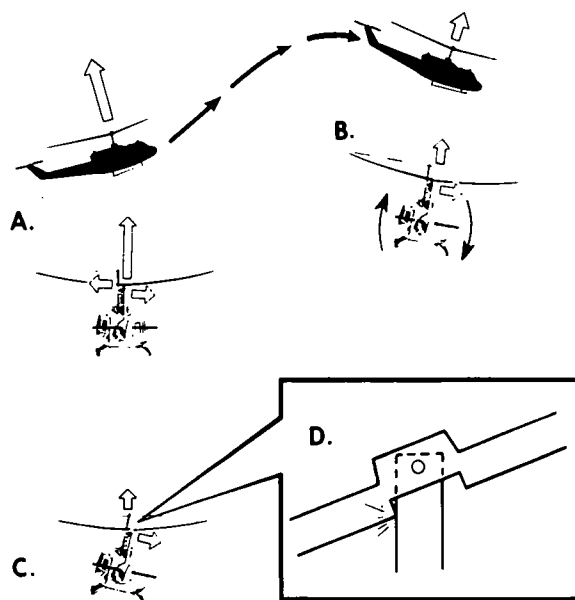
Mast bumping is directly related to how much the pilot allows the blade system to flap. In straight-and-level flight, blade flapping is minimal—perhaps 2 degrees under usual flight conditions. Flapping angles increase moderately with high forward speeds, at low rotor RPM, at high density altitudes, at high gross weights, and during turbulence. Aircraft maneuvering, such as sideslips or low-speed flight at extreme CG positions, can induce larger flapping angles.

□ Excessive flapping is most probable when pilots allow the aircraft to approach *low-G conditions*. Common maneuvers leading to low-G conditions include crossing a ridgeline during high speed terrain flight, masking and unmasking, acquiring or staying on a target, and recovery from a pullup. Each of these maneuvers has in common an application of forward cyclic or a reduction of collective pitch that unloads the main rotor. The combinations of down collective and forward cyclic that produce low-Gs essentially cancel the lift; and therefore thrust, produced by the main rotor. Absence of main rotor thrust makes lateral cyclic control ineffective, so lateral cyclic movement produces no change of fuselage attitude. The aircraft does not respond to lateral cyclic because the pilot gave up G loading on the rotor disk when the maneuver was initiated.

- Figure 10-2 illustrates what happens during the low-G condition. In sketch A, the helicopter rotor is loaded and all forces are in balance as in normal cruise or a steady state cyclic climb.

- Sketch B shows the helicopter in a low-G condition produced by an abrupt pilot input of forward cyclic. Note that the main rotor is unloaded; that is, thrust is reduced significantly. The aircraft is rolling to the right because tail rotor thrust is no longer offset by the main rotor thrust. Forces are not in balance because the pilot gave up rotor disk loading when the zero-G maneuver was initiated.

- Sketch C shows what happens when the pilot applies left lateral cyclic to counter the right roll. This is a normal pilot reaction to correct for a right roll; but, in this case, it is an incorrect reaction.



**FIGURE 10-2. ZERO-G MANEUVER
RESULTING IN MAST BUMPING.**

Because the rotor is unloaded, the fuselage does not follow the rotor disk and severe flapping results. The maximum design flapping angle is exceeded and mast bumping occurs as shown in sketch D.

- How should the pilot recover from the noseover maneuver which caused the low-G condition? Of course, the best method is to avoid the low-G condition by using more gradual forward cyclic. The rate and extent of cyclic motion should be adjusted to keep the rotor loaded at all times. Mast bumping is minimized by staying above $\frac{1}{2}$ G at all times, thereby preventing the low-G condition and tendency to roll right. However, if the rotor becomes unloaded during a low-G maneuver, it is absolutely essential to recover rotor thrust by *smoothly applying aft cyclic*. Once rotor thrust is restored, then left cyclic will be effective in rolling the aircraft to a level flight attitude.

□ Another possible cause of mast bumping is *engine failure*. If the pilot responds correctly to an engine failure, mast bumping will not occur. However, an incorrect pilot reaction could cause mast bumping.

● Assume the helicopter is flying in a normal cruise attitude. The longitudinal axis, and therefore the nose, is pitched down slightly and the rotor disk is tilted slightly forward. Viewed from the rear, the rotor disk is tilted slightly to the left to counter the tail rotor thrust to the right. The roll axis is located below the tail rotor thrust axis. From above, the main rotor is turning counterclockwise. Torque produces a clockwise force on the fuselage which is counteracted by tail rotor thrust to the right. All forces are balanced and the helicopter is in equilibrium.

● When the engine stops, the rotor RPM and airspeed begin to decay with some loss of altitude. Because the engine is no longer driving the main rotor and RPM is decreasing, the torque about the mast is diminishing. The tail rotor continues to thrust to the right causing the aircraft nose to yaw left. Tail rotor thrust is above the longitudinal axis and initiates fuselage roll to the right. Left yaw exposes the right side of the fuselage to the relative wind which aggravates the roll to the right.

● The pilot sees an abrupt change in aircraft attitude. The nose is down and yaws left. The aircraft appears to be in a roll to the right. Normal pilot reaction is to apply right pedal and left aft cyclic. Left

aft cyclic immediately tilts the rotor disk left and aft which results in larger flapping angles and possible mast bumping. The pilot has reacted to the symptom and not the primary problem. The symptom is the roll...the problem is power loss. The correct remedy is to lower collective pitch to maintain rotor RPM and apply right pedal to trim the aircraft. Avoid abrupt or very large cyclic corrections until the rotor RPM is back in the normal range.

□ A third possible cause of mast bumping is tail rotor failure. In the description that follows, assume that the failure causes tail rotor thrust to go to zero and only the tail fin remains to resist torque about the main rotor mast.

● At the instant of tail rotor failure, when antitorque thrust goes to zero, the aircraft yaws right and rolls left. The yaw attitude exposes the left side and nose of the aircraft to the relative wind which contributes to left roll and a nose-down attitude. Absence of tail rotor thrust also aggravates the tendency to roll left.

● The pilot sees an abrupt right yaw, left roll and nose-down attitude. Normal pilot reaction is to move the cyclic aft right and apply left pedal. With the fuselage already rolling left, right cyclic tilts the rotor disk right toward the fuselage and drastically increases blade flapping. Mast bumping becomes a possibility. The pilot has reacted to the symptom and not the primary problem. The symptom is the nose low, and roll left...the problem is torque

tending to yaw the aircraft. Correct pilot reaction for this failure is immediate reduction in power to reduce torque. This will reduce the yaw, allowing time to correct for the roll tendency. With reduced throttle and collective, keep airspeed slightly above the normal autorotative glide speed. Experiment with gentle throttle and pitch application to see if some degree of powered flight can be resumed.

The single most important message regarding all types of mast bumping is that the pilot can prevent mast bumping by the way the aircraft is handled. Control inputs must be smooth and gradual even in different situations such as low-G situation. It is the abrupt, full range pilot control inputs combined with low-G conditions, engine failure, or tail rotor failure that cause mast bumping.

APPENDIX A**REFERENCES**

Department of the Army Pamphlets of the 310-series should be consulted frequently for latest changes or revisions of the references given in this appendix and for new publications relating to the material covered in this publication.

ARMY REGULATIONS (AR)

95-series (Military Publication Indexes)

310-series (Military Publications)

DEPARTMENT OF THE ARMY PAMPHLETS (DA PAM)

310-series (Military Publication Indexes)

FIELD MANUALS (FM)

1-5 Instrument Flying and Navigation for Army Aviators

1-30 Meteorology for Army Aviators

90-1 Employment of Army Aviation Units in a High Threat Environment

TECHNICAL MANUALS (TM)

55-1520-series (Operator's manual for the helicopter being flown)

TRAINING CIRCULARS (TC)

1-4	Helicopter Gunnery
1-10	Mountain Flying Sense
1-12	Cold Weather Flying Sense
1-27	Preparation of the UH-1M for Night Flight
1-29	Preparation of the UH-1 for Night Flight
1-30	Preparation of the AH-1 for Night Flight
1-31	Preparation of the OH-58 for Night Flight
1-32	Preparation of the CH-47 for Night Flight
1-33	Preparation of the OH-6 for Night Flight
1-135*	Aircrew Training Manual, Utility Helicopter
1-136*	Aircrew Training Manual, Attack Helicopter
1-137*	Aircrew Training Manual, Observation Helicopter
1-139*	Aircrew Training Manual, Cargo Helicopter

*During FY 79 and FY 80 the second draft of each Aircrew Training Manual is being used Armywide for aviator training. The final Department of the Army publication of each Aircrew Training Manual should be available in FY 80-4 and will be used for aviator training in FY 81 and subsequent years. Draft editions are available through Commander, USAAVNC, ATTN: ATZQ-TD-TL Fort Rucker, AL 36362 (AUTOVON 558-4619/7120).

INTERNATIONAL AGREEMENTS
NATO

STANAG 3379	In Flight Visual Signals
STANAG 3597	Helicopter Tactical or Non-Permanent Landing Sites
STANAG 3627	Helicopter Day and Night Tactical Formation Flying
QWG-AVN	Terrain Flying (concept paper)
ASCC 44/46	Load Preparation for External Carriage by Helicopters

APPENDIX B

COMMENTARY NOTES ON NIGHT VISION

Because of the technical medical nature of night vision, commentary notes corresponding to the superscript numerals in chapter 6 are provided. These notes are not essential to a practical understanding of the text, but are provided for personnel requiring an in-depth explanation of specific technical terminology.

¹As a result of the fovea's exclusive cone representation, the absolute blind spot is from 2° to 2.5° wide. However, since the area immediately around the fovea is predominated by cones, it too is relatively insensitive. Thus, the functional or operational blind spot affects an area from 5° to 10° wide in the center of the visual field.

²The night blind spot should not be confused with the day blind spot. The day blind spot results from the optic disc's position on the retina. The optic disc is devoid of light sensitive receptors. However, due to the overlap of binocular vision, the day blind spot is not noticed. The night blind spot is centrally located. As a result, it is noticed even when both eyes are used.

³Each eye has an identical night blind spot so that viewing with one eye closed would produce the same limitation as binocular vision except that the day blind spot would also become apparent.

⁴The use of the word "projected" is used figuratively in that the effect of the blind spot is as if it were being projected like a ray of blindness, obscuring larger areas with increasing distance from the viewer.

⁵Measurement of light levels can be a complex and confusing study. There are many different units of light measurement that are used for varying scientific, engineering, and industrial applications. The terms of measurement are usually unfamiliar to all but the few individuals who work directly with light measurement problems. For this reason, the following definitions are provided to permit interpretation of data that may be presented to the readers from different sources:

☐ *Illumination.* This is the amount of light striking a surface at some distance from a source. The common unit of measure is the foot-candle (ft-c). A foot-candle is the density of light falling on the inner surface of a sphere of 1-foot radius when a point source of light with an intensity of one international candle (c) is placed at the center of the sphere.

☐ *Luminance.* For visual displays, this is an important measurement. It is the amount of light per unit area reflected from

or emitted by a surface. Although this measurement is frequently called brightness, strictly speaking, brightness is influenced by contrast, adaptation, and other factors besides the physical energy in the stimulus.

□ *Reflectance.* This is the relationship between illumination reaching a surface and the resulting luminance. A perfectly diffusing and reflecting surface would be one that absorbs no light and scatters the illumination in the manner of a perfect flat surface. Such a surface would have a reflectance of 100 percent. If illuminated by 1 ft-c, it would have a luminance of 1 foot-Lambert (ft-L) from all viewing angles. In actual practice, the maximum reflectance achievable for a nearly perfectly diffusing surface is about 75 percent.

□ *Contrast.* This is a measure of luminance difference between that of a target and its background. Contrast can vary from 100 percent (positive) to zero for targets darker than their backgrounds and from zero to the infinity (negative) for targets brighter than their backgrounds.

⁶ Visual acuity of 20/200 or less is equivalent to being limited to seeing objects the size of or larger than the big "E" on visual acuity testing charts from a distance of 20 feet.

⁷ The technique of offcenter vision applies only to surveillance of targets that are minimally illuminated or luminous. Under these conditions, cone vision is not stimulated. If an object or target is just bright enough to be seen by central vision (thus of sufficient intensity to stimulate the cones) and needs to be seen with considerable detail, then central vision is best used until the object or target begins to fade. At this point, the target should be redetected using offcenter vision and retained until central vision recovers sufficiently to permit further observation.

⁸ *Light level.* Light level is the ambient light produced by natural sources of sky light combined with any moonlight. Illumination is normally expressed in foot-candles (note 5). Light level is categorized as follows:

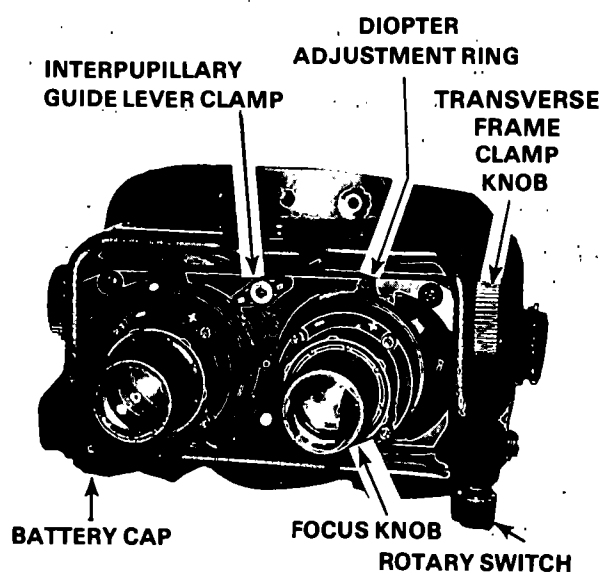
□ *Low light level*—Illuminance of night ambient light less than 2.5×10^{-4} foot-candles.

□ *Mid light level*—Illuminance of night ambient light between 2.5×10^{-4} and 3.0×10^{-3} foot-candles.

□ *High light level*—Illuminance of night ambient light greater than 3.0×10^{-3} foot-candles.

APPENDIX C

NIGHT VISION GOGGLES AN/PVS-5 OPERATING INSTRUCTIONS



NIGHT VISION GOGGLES (AN/PVS-5).

☐ Keep protective caps on eyepiece and objective lenses at all times when not in use.

☐ Operate night vision goggles only under nighttime conditions.

☐ Do not look at high intensity light sources with the goggles.

CAUTION: This equipment is a precision electro-optical instrument and must be handled carefully.

BATTERY INSTALLATION

- ☐ Unscrew battery cap.
- ☐ Insert battery, recessed end (+ end) first, into the battery compartment.
- ☐ Replace battery cap and tighten firmly to insure watertight seal.

OPERATION UNDER
USUAL CONDITIONS

The following should be performed in a dark room or other dark area with an observer in attendance who has been dark-adapted for a minimum of 15 minutes.

- ☐ *Distant viewing operations.*
 - Remove objective lens protective caps.
 - Set rotary switch to ON and observe (after a delay) that a green glow is visible in each eyepiece.
 - Loosen lever clamp and adjust monoculars for proper distance between the eyes. Retighten lever clamp.

- Loosen clamp knobs and adjust the binocular assembly until the eyepieces are located a comfortable distance from the eyes. Retighten both clamp knobs.

- Turn focus knob full counterclockwise on each objective lens for distant viewing. Adjust for clearest view.

- Close left eye and adjust the right diopter and adjusting ring for clearest view.

- Close right eye and adjust the left diopter adjusting ring for clearest view.

- Have observer check carefully for stray light that is visible at edges of face cushion assembly.

- Pass your hand directly in front of the night vision goggles to determine if infrared (IR) illuminator has been turned on. If contrast appears extra bright, rotary switch is in IR position and should be turned to ON position.

☐ *Reading use operation.*

Turn focus knob on each objective lens fully clockwise to obtain sharp focus at a distance of about 25 centimeters (10 inches). At this setting of lenses, distant objects will not be in focus. The lens may be individually adjusted to obtain sharp focus on objects at any distance between 25 centimeters (10 inches) and infinity.

☐ *IR illuminator operation.*

- Turn rotary switch to IR and observe that the area in your immediate front is illuminated.

- As the IR illuminator is turned on, the momentary flash that you see is normal.

☐ *Installation and removal of demisting shield.* If the eyepieces fog up during operation, install the demisting shield.

- *Installation.* Snap demisting shields over eyepieces. Be careful not to smudge eyepieces or demisting shields.

- *Removal.* Remove demisting shield by grasping shield and pulling.

☐ *Standby operation.*

- Turn rotary switch to OFF and observe that the green flow disappears immediately from each eyepiece. Do not remove the night vision goggles unless the rotary switch is in OFF position.

- Remove the night vision goggles by holding face mask assembly with one hand and removing headstrap assembly with the other hand.

- The neck cord allows you to rest the night vision goggles on your chest ready for instant use.

☐ *Shutdown status.*

- Replace objective lens protective caps.

- Replace eyepiece lens protective caps.

- Make certain rotary switch is in OFF position.

- Unscrew battery cap.

- Remove battery.
- Replace battery cap.
- Place night vision goggles and battery in carrying case and secure latch.
- Place carrying case in fitted portion of storage case.
- Latch storage case.

OPERATION IN FREEZING TEMPERATURES

- ☐ Install demist shields.
- ☐ Remove battery cap from night vision goggles. Stretch battery cap in plastic retainer over button to remove battery cap.
- ☐ Remove battery from night vision goggles.
- ☐ Place battery in arctic kit battery holder, recessed end (+ end) in first.
- ☐ Screw the removed battery cap on arctic battery holder.
- ☐ Screw arctic kit cap on night vision goggles.
- ☐ Place arctic kit battery holder in inside pocket next to body.
- ☐ Keep spare batteries in the inside pocket next to body.

OPERATION IN DUSTY OR SANDY AREAS

CAUTION: Operation in dusty or sandy areas can cause pitting and scratching of optical elements and damage to mechanical components unless the following precautions are observed.

- ☐ Avoid pointing the night vision goggles into the wind unless necessary for operation.
- ☐ Keep carrying case and storage case closed unless removing or replacing items.
- ☐ Insure that all dust and sand are removed from the goggles after operation.

OPERATION IN RAINY OR HUMID CONDITIONS

CAUTION: Operation in rainy or humid conditions can cause corrosion and deterioration of the night vision goggles unless the following precautions are observed.

- ☐ Install demisting shields.
- ☐ Keep the carrying case closed unless removing or replacing items.
- ☐ Dry all parts after exposure to rain or high humidity.
- ☐ Do not store night vision goggles in a wet carrying case or a wet storage case.

OPERATION IN SALT WATER AREAS

CAUTION: Operation in salt water areas can cause corrosion of the goggles unless the following precautions are observed.

☐ After exposure to salt water, clean with fresh water.

☐ Unsnap the headstrap assembly and face cushion assembly and clean separately. Night vision goggles may be immersed in water. The face cushion assembly will normally air-dry in an hour.

☐ Dry all parts completely. Do not disassemble.

☐ Use lens tissue to clean the objective lenses and the eyepiece lenses.

APPENDIX D

HEMISPHERICAL PREDICTION

GENERAL

To operate at night at low altitudes, aviation missions must be flown when the highest level of ambient light exists. To determine when the highest level of light exists, you should refer to the light level calendar. In order to construct a light level calendar, you must first determine the altitude of the moon for certain hours of the night. With this information and the percent of illumination of the moon, you can enter the brightness chart to determine the light level. After determining the light level, a graph can be drawn which gives a visual representation of the different light levels during a night. The procedures for determining the altitude of the moon are as follows.

☐ You must first obtain a copy of the Air Almanac, which is available from the Air Force Weather Station serving your unit; or by writing to the Superintendent of Documents, US Government Printing Office, Washington, D.C. 20402. It is published by the US Naval Observatory and covers a period of 6 months. The entire publication contains useful information; however, in computing the altitude of the moon, only one column of data is used. This data appears on the orange pages with a page for the a.m. and p.m. hours for each day of the 6-month period (table D-1). The required data is located beneath the columns identified as "MOON." The left side of each page identifies the time in minutes and hours. For the purpose of computing the moon altitude, the data listed adjacent to the whole hour is

TABLE D-1. THE AIR ALMANAC.

(DAY 340) GREENWICH A. M. 1978 DECEMBER 6 (WEDNESDAY) 679

GMT	SUN	ARIES	VENUS-4.3	JUPITER-2.0	SATURN 1.1	MOON	Lat	Moon-rise	Diff
	GHA Dec	GHA °	GHA Dec	GHA Dec	GHA Dec	GHA Dec			
00 00	182 18.7 S22 25.2	74 25.5	217 52 S12 47	302 58 N18 31	268 51 N 8 03	102 49 S 9 33	N		
10	184 48.7 25.3	76 55.9	220 22	305 28	271 22	105 13 31		h m	m
20	187 18.7 25.3	79 26.3	222 52	307 59	273 52	107 38 29	72	13 13	-03
30	189 48.6 25.4	81 56.7	225 22	310 29	276 22	110 03 28	70	13 02	+01
40	192 18.6 25.5	84 27.1	227 53	313 00	278 53	112 27 26	68	12 53	04
50	194 48.5 25.5	86 57.5	230 23	315 30	281 23	114 52 25	66	12 45	06
01 00	197 18.5 S22 25.6	89 27.9	232 53 S12 46	318 01 N18 31	283 54 N 8 03	117 17 S 9 23	64	12 39	08
10	199 48.4 25.6	91 58.4	235 23	320 31	286 24	119 41 21	62	12 34	09
20	202 18.4 25.7	94 28.8	237 54	323 01	288 54	122 06 20	60	12 29	11
30	204 48.4 25.7	96 59.2	240 24	325 32	291 25	124 31 18	58	12 25	12
40	207 18.3 25.8	99 29.6	242 54	328 02	293 55	126 55 16	56	12 21	13
50	209 48.3 25.8	102 00.0	245 25	330 33	296 26	129 20 15	54	12 18	14
02 00	212 18.2 S22 25.9	104 30.4	247 55 S12 46	333 03 N18 31	298 56 N 8 03	131 45 S 9 13	52	12 15	15
10	214 48.2 25.9	107 00.8	250 25	335 34	301 26	134 09 11	50	12 12	16
20	217 18.1 26.0	109 31.2	252 55	338 04	303 57	136 34 10	48	12 06	17
30	219 48.1 26.0	112 01.6	255 26	340 34	306 27	138 59 08	46	12 01	19
40	222 18.0 26.1	114 32.1	257 56	343 05	308 58	141 23 07	44	11 56	20
50	224 48.0 26.1	117 02.5	260 26	345 35	311 28	143 48 05	42	11 52	21
03 00	227 18.0 S22 26.2	119 32.9	262 57 S12 46	348 06 N18 31	313 58 N 8 03	146 13 S 9 03	40	11 45	23
10	229 47.9 26.2	122 03.3	265 27	350 36	316 29	148 37 02	38	11 39	25
20	232 17.9 26.3	124 33.7	267 57	353 06	318 59	151 02 00	36	11 34	26
30	234 47.8 26.3	127 04.1	270 27	355 37	321 30	153 27 8 58	34	11 28	28
40	237 17.8 26.4	129 34.5	272 58	358 07	324 00	155 51 57	32	11 22	29
50	239 47.7 26.4	132 04.9	275 28	0 38	326 30	158 16 55	30	11 15	31
04 00	242 17.7 S22 26.5	134 35.3	277 58 S12 46	3 08 N18 31	329 01 N 8 03	160 41 S 8 53	28	11 11	32
10	244 47.7 26.5	137 05.7	280 28	5 39	331 31	163 05 52	26	11 07	34
20	247 17.6 26.6	139 36.2	282 59	8 09	334 01	165 30 50	24	11 02	35
30	249 47.6 26.6	142 06.6	285 29	10 39	336 32	167 55 49	22	10 56	37
40	252 17.5 26.7	144 37.0	287 59	13 10	339 02	170 20 47	20	10 53	38
50	254 47.5 26.7	147 07.4	290 29	15 40	341 33	172 44 45	18	10 49	39
05 00	257 17.4 S22 26.8	149 37.8	293 00 S12 46	18 11 N18 31	344 03 N 8 03	175 09 S 8 44	16	10 46	40
10	259 47.4 26.8	152 08.2	295 30	20 41	346 33	177 34 42	14	10 42	41
20	262 17.3 26.9	154 38.6	298 00	23 12	349 04	179 58 40	12	10 38	42
30	264 47.3 26.9	157 09.0	300 31	25 42	351 34	182 23 39	10		
40	267 17.3 27.0	159 39.4	303 01	28 12	354 05	184 48 37	8		
50	269 47.2 27.0	162 09.9	305 31	30 43	356 35	187 12 35	6		
06 00	272 17.2 S22 27.1	164 40.3	308 01 S12 46	33 13 N18 31	359 05 N 8 03	189 37 S 8 34	4		
10	274 47.1 27.1	167 10.7	310 32	35 44	1 36	192 02 32	2		
20	277 17.1 27.2	169 41.1	313 02	38 14	4 06	194 27 30	0		
30	279 47.0 27.2	172 11.5	315 32	40 45	6 37	196 51 29	0		
40	282 17.0 27.3	174 41.9	318 02	43 15	9 07	199 16 27	0		
50	284 47.0 27.3	177 12.3	320 33	45 45	11 37	201 41 25	0		
07 00	287 16.9 S22 27.4	179 42.7	323 03 S12 46	48 16 N18 31	14 08 N 8 03	204 05 S 8 24	0		
10	289 46.9 27.4	182 13.1	325 33	50 46	16 38	206 30 22	0		
20	292 16.8 27.5	184 43.6	328 04	53 17	19 09	208 55 20	0		
30	294 46.8 27.6	187 14.0	330 34	55 47	21 39	211 20 19	0		
40	297 16.7 27.6	189 44.4	333 04	58 18	24 09	213 44 17	0		
50	299 46.7 27.7	192 14.8	335 34	60 48	26 40	216 09 15	0		
08 00	302 16.6 S22 27.7	194 45.2	338 05 S12 45	63 18 N18 32	29 10 N 8 03	218 34 S 8 14	0		
10	304 46.6 27.8	197 15.6	340 35	65 49	31 41	220 59 12	0		
20	307 16.6 27.8	199 46.0	343 05	68 19	34 11	223 23 10	0		
30	309 46.5 27.9	202 16.4	345 35	70 50	36 41	225 48 09	0		
40	312 16.5 27.9	204 46.8	348 06	73 20	39 12	228 13 07	0		
50	314 46.4 28.0	207 17.2	350 36	75 50	41 42	230 38 05	0		
09 00	317 16.4 S22 28.0	209 47.6	353 06 S12 45	78 20 N18 32	44 12 N 8 03	233 02 S 8 03	0		
10	319 46.4 28.0	212 18.0	355 36	80 50	46 42	235 27 01	0		
20	322 16.4 28.0	214 48.4	358 06	83 20	49 12	237 52 00	0		
30	324 46.4 28.0	217 18.8	360 36	85 50	51 42	240 17 00	0		
40	327 16.4 28.0	219 49.2	363 06	88 20	54 12	242 42 00	0		
50	329 46.4 28.0	222 19.6	365 36	90 50	56 42	245 07 00	0		

required. Remember, all times in the almanac are Greenwich mean time (GMT). To compute the moon altitude from your position, you must convert local time to GMT and enter the tables at the appropriate day and hour.

□ Two columns appear under the word "MOON", "GHA" and "Dec." The Greenwich hour angle (GHA) is the longitude of the moon at the time identified. The GHA is expressed in degrees from 0-360 as measured westerly from Greenwich England. Declination (Dec) is the latitude of the moon at the time identified. It is expressed in degrees from 0-90 N and 0-90 S latitudes. When computing the moon's altitude, minus (-) values will be applied to south latitudes. The values for the GHA and Dec are identified in degrees and minutes. When applying these values to the moon altitude formula, round off to the closest whole number.

□ To compute the altitude of the moon as observed from your location, apply the known values into the moon altitude formula. If a calculator with trigonometric functions is available, the problem is simplified; however, if it must be computed by long hand, the trigonometric values must be obtained from the trigonometric function tables (tables D-2, D-3).

$$\text{MOON ALTITUDE} = \text{ARCSIN} [\text{COS (GHA-LONG) COS (LAT) COS (DEC) + SIN (LAT) SIN (DEC)}]$$

The following example describes how to solve the moon altitude equation:

$$\text{Moon Altitude} = \text{Arcsin} [\text{Cos (GHA-long) Cos (Lat) Cos (Dec) + Sin (Lat) Sin (Dec)}]$$

$$\text{Arcsin} = \text{Cos (146-86) Cos (31) Cos (-9) + Sin (31) Sin (-9)}$$

$$\text{Arcsin} = \text{Cos (+60) Cos (31) Cos (-9) + Sin (31) Sin (-9)}$$

$$\text{Arcsin} = [(.50) (.86) (.99) + (.52 (-.16))]$$

$$\text{Arcsin} = (+.43) + (-.08)$$

$$= \text{Arcsin (+.35)}$$

$$\text{Moon Altitude} = 20^\circ$$

Step 1

Identify the longitude and latitude of your position to the closet degree. This can be determined from any geographic map. Observer south latitudes will be entered as minus (-) values. Assume your position is at Cairns Army Airfield, Fort Rucker, Alabama, the geographic location is:

$$\text{Longitude} = 86^\circ$$

$$\text{Latitude} = 31^\circ\text{N}$$

Step 2

Identify the GHA and MOON Dec. The desired date-time group for determining the altitude of the moon is 5 December at 2100 hours. Convert local time to Greenwich mean time. If you are located in Alabama, add 6 hours to determine the GMT. To determine the GHA and MOON Dec, enter the table for 6 December at 0300 hours.

$$\text{GHA} = 146^\circ$$

$$\text{MOON Dec} = -9^\circ$$

TABLE D-2. TRIGONOMETRIC FUNCTION TABLES (SINE).

OPEN FOR
FOLDOUT

TABLE D-2. TRIGONOMETRIC FUNCTION TABLES (SINE).

DEGREES				SINE	DEGREES				SINE	DEGREES				SINE	DEGREES				SINE
0	+180	-360		.0000	+23	+157	-203	-337	+.3907	+46	+134	-226	-314	+.7193	+69	+111	-249	-291	+.9336
0	-180	+360		.0000	-23	-157	+203	+337	-.3907	-46	-134	+226	+314	-.7193	-69	-111	+249	+291	-.9336
+1	+179	-181	-359	+.0175	+24	+156	-204	-336	+.4067	+47	+133	-227	-313	+.7314	+70	+110	-250	-290	+.9397
-1	-179	+181	+359	-.0175	-24	-156	+204	+336	-.4067	-47	-133	+227	+313	-.7314	-70	-110	+250	+290	-.9397
+2	+178	-182	-358	+.0349	+25	+155	-205	-335	+.4226	+48	+132	-228	-312	+.7413	+71	+109	-251	-289	+.9455
-2	-178	+182	+358	-.0349	-25	-155	+205	+335	-.4226	-48	-132	+228	+312	-.7413	-71	-109	+251	+289	-.9455
+3	+177	-183	-357	+.0523	+26	+154	-206	-334	+.4384	+49	+131	-229	-311	+.7547	+72	+108	-252	-288	+.9511
-3	-177	+183	+357	-.0523	-26	-154	+206	+334	-.4384	-49	-131	+229	+311	-.7547	-72	-108	+252	+288	-.9511
+4	+176	-184	-356	+.0698	+27	+153	-207	-333	+.4540	+50	+130	-230	-310	+.7660	+73	+107	-253	-287	+.9563
-4	-176	+184	+356	-.0698	-27	-153	+207	+333	-.4540	-50	-130	+230	+310	-.7660	-73	-107	+253	+287	-.9563
+5	+175	-185	-355	+.0875	+28	+152	-208	-332	+.4695	+51	+129	-231	-309	+.7771	+74	+106	-254	-286	+.9613
-5	-175	+185	+355	-.0875	-28	-152	+208	+332	-.4695	-51	-129	+231	+309	-.7771	-74	-106	+254	+286	-.9613
+6	+174	-186	-354	+.1051	+29	+151	-209	-331	+.4848	+52	+128	-232	-308	+.7880	+75	+105	-255	-285	+.9659
-6	-174	+186	+354	-.1051	-29	-151	+209	+331	-.4848	-52	-128	+232	+308	-.7880	-75	-105	+255	+285	-.9659
+7	+173	-187	-353	+.1228	+30	+150	-210	-330	+.5000	+53	+127	-233	-307	+.7886	+76	+104	-256	-284	+.9703
-7	-173	+187	+353	-.1228	-30	-150	+210	+330	-.5000	-53	-127	+233	+307	-.7886	-76	-104	+256	+284	-.9703
+8	+172	-188	-352	+.1405	+31	+149	-211	-329	+.5150	+54	+126	-234	-306	+.8090	+77	+103	-257	-283	+.9744
-8	-172	+188	+352	-.1405	-31	-149	+211	+329	-.5150	-54	-126	+234	+306	-.8090	-77	-103	+257	+283	-.9744
+9	+171	-189	-351	+.1564	+32	+148	-212	-328	+.5299	+55	+125	-235	-305	+.8192	+78	+102	-258	-282	+.9781
-9	-171	+189	+351	-.1564	-32	-148	+212	+328	-.5299	-55	-125	+235	+305	-.8192	-78	-102	+258	+282	-.9781
+10	+170	-190	-350	+.1736	+33	+147	-213	-327	+.5446	+56	+124	-236	-304	+.8290	+79	+101	-259	-281	+.9816
-10	-170	+190	+350	-.1736	-33	-147	+213	+327	-.5446	-56	-124	+236	+304	-.8290	-79	-101	+259	+281	-.9816
+11	+169	-191	-349	+.1908	+34	+146	-214	-326	+.5592	+57	+123	-237	-303	+.8387	+80	+100	-260	-280	+.9848
-11	-169	+191	+349	-.1908	-34	-146	+214	+326	-.5592	-57	-123	+237	+303	-.8387	-80	-100	+260	+280	-.9848
+12	+168	-192	-348	+.2079	+35	+145	-215	-325	+.5736	+58	+122	-238	-302	+.8480	+81	+99	-261	-279	+.9877
-12	-168	+192	+348	-.2079	-35	-145	+215	+325	-.5736	-58	-122	+238	+302	-.8480	-81	-99	+261	+279	-.9877
+13	+167	-193	-347	+.2250	+36	+144	-216	-324	+.5878	+59	+121	-239	-301	+.8572	+82	+98	-262	-278	+.9903
-13	-167	+193	+347	-.2250	-36	-144	+216	+324	-.5878	-59	-121	+239	+301	-.8572	-82	-98	+262	+278	-.9903
+14	+166	-194	-346	+.2419	+37	+143	-217	-323	+.6018	+60	+120	-240	-300	+.8660	+83	+97	-263	-277	+.9925
-14	-166	+194	+346	-.2419	-37	-143	+217	+323	-.6018	-60	-120	+240	+300	-.8660	-83	-97	+263	+277	-.9925
+15	+165	-195	-345	+.2588	+38	+142	-218	-322	+.6157	+61	+119	-241	-299	+.8746	+84	+96	-264	-276	+.9945
-15	-165	+195	+345	-.2588	-38	-142	+218	+322	-.6157	-61	-119	+241	+299	-.8746	-84	-96	+264	+276	-.9945
+16	+164	-196	-344	+.2756	+39	+141	-219	-321	+.6293	+62	+118	-242	-298	+.8829	+85	+95	-265	-275	+.9962
-16	-164	+196	+344	-.2756	-39	-141	+219	+321	-.6293	-62	-118	+242	+298	-.8829	-85	-95	+265	+275	-.9962
+17	+163	-197	-343	+.2924	+40	+140	-220	-320	+.6428	+63	+117	-243	-297	+.8910	+86	+94	-266	-274	+.9976
-17	-163	+197	+343	-.2924	-40	-140	+220	+320	-.6428	-63	-117	+243	+297	-.8910	-86	-94	+266	+274	-.9976
+18	+162	-198	-342	+.3090	+41	+139	-221	-319	+.6561	+64	+116	-244	-296	+.8988	+87	+93	-267	-273	+.9986
-18	-162	+198	+342	-.3090	-41	-139	+221	+319	-.6561	-64	-116	+244	+296	-.8988	-87	-93	+267	+273	-.9986
+19	+161	-199	-341	+.3256	+42	+138	-222	-318	+.6691	+65	+115	-245	-295	+.9063	+88	+92	-268	-272	+.9994
-19	-161	+199	+341	-.3256	-42	-138	+222	+318	-.6691	-65	-115	+245	+295	-.9063	-88	-92	+268	+272	-.9994
+20	+160	-200	-340	+.3420	+43	+137	-223	-317	+.6820	+66	+114	-246	-294	+.9135	+89	+91	-269	-271	+.9998
-20	-160	+200	+340	-.3420	-43	-137	+223	+317	-.6820	-66	-114	+246	+294	-.9135	-89	-91	+269	+271	-.9998
+21	+159	-201	-339	+.3584	+44	+136	-224	-316	+.6947	+67	+113	-247	-293	+.9205	+90			-270	+.1000
-21	-159	+201	+339	-.3584	-44	-136	+224	+316	-.6947	-67	-113	+247	+293	-.9205	-90			+270	-.1000
+22	+158	-202	-338	+.3746	+45	+135	-225	-315	+.7071	+68	+112	-248	-292	+.9272					
-22	-158	+202	+338	-.3746	-45	-135	+225	+315	-.7071	-68	-112	+248	+292	-.9272					

TABLE D-3. TRIGONOMETRIC FUNCTION TABLES (COSINE).

DEGREES				COSINE	DEGREES				COSINE	DEGREES				COSINE	DEGREES				COSINE
+ 0	+360			+1.0000	+ 23	- 23	+337	-337	+ .9205	+ 46	- 46	+314	-314	+ .6947	+ 69	- 69	+291	-291	+ .3584
- 0	-360			+1.0000	+157	-157	+203	-203	+ .9205	+134	-134	+226	-226	+ .6947	+111	-111	+249	-249	+ .3584
+ 1	- 1	+359	-359	+ .9998	+ 24	- 24	+336	-336	+ .9135	+ 47	- 47	+313	-313	+ .6820	+ 70	- 70	+290	-290	+ .3420
+179	-179	+181	-181	+ .9998	+156	-156	+204	-204	+ .9135	+133	-133	+227	-227	+ .6820	+110	-110	+250	-250	+ .3420
+ 2	- 2	+358	-358	+ .9994	+ 25	- 25	+335	-335	+ .9063	+ 48	- 48	+312	-312	+ .6691	+ 71	- 71	+289	-289	+ .3256
+178	-178	+182	-182	+ .9994	+155	-155	+205	-205	+ .9063	+132	-132	+228	-228	+ .6691	+109	-109	+251	-251	+ .3256
+ 3	- 3	+357	-357	+ .9986	+ 26	- 26	+334	-334	+ .8988	+ 49	- 49	+311	-311	+ .6561	+ 72	- 72	+288	-288	+ .3090
+177	-177	+183	-183	+ .9986	+154	-154	+206	-206	+ .8988	+131	-131	+229	-229	+ .6561	+108	-108	+252	-252	+ .3090
+ 4	- 4	+356	-356	+ .9976	+ 27	- 27	+333	-333	+ .8910	+ 50	- 50	+310	-310	+ .6428	+ 73	- 73	+287	-287	+ .2924
+176	-176	+184	-184	+ .9976	+153	-153	+207	-207	+ .8910	+130	-130	+230	-230	+ .6428	+107	-107	+253	-253	+ .2924
+ 5	- 5	+355	-355	+ .9962	+ 28	- 28	+332	-332	+ .8829	+ 51	- 51	+309	-309	+ .6293	+ 74	- 74	+286	-286	+ .2756
+175	-175	+185	-185	+ .9962	+152	-152	+208	-208	+ .8829	+129	-129	+231	-231	+ .6293	+106	-106	+254	-254	+ .2756
+ 6	- 6	+354	-354	+ .9945	+ 29	- 29	+331	-331	+ .8746	+ 52	- 52	+308	-308	+ .6157	+ 75	- 75	+285	-285	+ .2588
+174	-174	+186	-186	+ .9945	+151	-151	+209	-209	+ .8746	+128	-128	+232	-232	+ .6157	+105	-105	+255	-255	+ .2588
+ 7	- 7	+353	-353	+ .9925	+ 30	- 30	+330	-330	+ .8660	+ 53	- 53	+307	-307	+ .6018	+ 76	- 76	+284	-284	+ .2419
+173	-173	+187	-187	+ .9925	+150	-150	+210	-210	+ .8660	+127	-127	+233	-233	+ .6018	+104	-104	+256	-256	+ .2419
+ 8	- 8	+352	-352	+ .9903	+ 31	- 31	+329	-329	+ .8572	+ 54	- 54	+306	-306	+ .5878	+ 77	- 77	+283	-283	+ .2250
+172	-172	+188	-188	+ .9903	+149	-149	+211	-211	+ .8572	+126	-126	+234	-234	+ .5878	+103	-103	+257	-257	+ .2250
+ 9	- 9	+351	-351	+ .9877	+ 32	- 32	+328	-328	+ .8480	+ 55	- 55	+305	-305	+ .5736	+ 78	- 78	+282	-282	+ .2079
+171	-171	+189	-189	+ .9877	+148	-148	+212	-212	+ .8480	+125	-125	+235	-235	+ .5736	+102	-102	+258	-258	+ .2079
+10	-10	+350	-350	+ .9843	+ 33	- 33	+327	-327	+ .8387	+ 56	- 56	+304	-304	+ .5592	+ 79	- 79	+281	-281	+ .1908
+170	-170	+190	-190	+ .9843	+147	-147	+213	-213	+ .8387	+124	-124	+236	-236	+ .5592	+101	-101	+259	-259	+ .1908
+11	-11	+349	-349	+ .9816	+ 34	- 34	+326	-326	+ .8290	+ 57	- 57	+303	-303	+ .5446	+ 80	- 80	+280	-280	+ .1736
+169	-169	+191	-191	+ .9816	+146	-146	+214	-214	+ .8290	+123	-123	+237	-237	+ .5446	+100	-100	+260	-260	+ .1736
+12	-12	+348	-348	+ .9781	+ 35	- 35	+325	-325	+ .8192	+ 58	- 58	+302	-302	+ .5299	+ 81	- 81	+279	-279	+ .1564
+168	-168	+192	-192	+ .9781	+145	-145	+215	-215	+ .8192	+122	-122	+238	-238	+ .5299	+ 99	- 99	+261	-261	+ .1564
+13	-13	+347	-347	+ .9744	+ 36	- 36	+324	-324	+ .8090	+ 59	- 59	+301	-301	+ .5150	+ 82	- 82	+278	-278	+ .1392
+167	-167	+193	-193	+ .9744	+144	-144	+216	-216	+ .8090	+121	-121	+239	-239	+ .5150	+ 98	- 98	+262	-262	+ .1392
+14	-14	+346	-346	+ .9703	+ 37	- 37	+323	-323	+ .7986	+ 60	- 60	+300	-300	+ .5000	+ 83	- 83	+277	-277	+ .1219
+166	-166	+194	-194	+ .9703	+143	-143	+217	-217	+ .7986	+120	-120	+240	-240	+ .5000	+ 97	- 97	+263	-263	+ .1219
+15	-15	+345	-345	+ .9659	+ 38	- 38	+322	-322	+ .7880	+ 61	- 61	+240	-240	+ .4848	+ 84	- 84	+276	-276	+ .1045
+165	-165	+195	-195	+ .9659	+142	-142	+218	-218	+ .7880	+119	-119	+241	-241	+ .4848	+ 96	- 96	+264	-264	+ .1045
+16	-16	+344	-344	+ .9613	+ 39	- 39	+321	-321	+ .7771	+ 62	- 62	+298	-298	+ .4695	+ 85	- 85	+275	-275	+ .0872
+164	-164	+196	-196	+ .9613	+141	-141	+219	-219	+ .7771	+118	-118	+242	-242	+ .4695	+ 95	- 95	+265	-265	+ .0872
+17	-17	+343	-343	+ .9563	+ 40	- 40	+320	-320	+ .7660	+ 63	- 63	+297	-297	+ .4540	+ 86	- 86	+274	-274	+ .0698
+163	-163	+197	-197	+ .9563	+140	-140	+220	-220	+ .7660	+117	-117	+243	-243	+ .4540	+ 94	- 94	+266	-266	+ .0698
+18	-18	+342	-342	+ .9511	+ 41	- 41	+319	-319	+ .7547	+ 64	- 64	+296	-296	+ .4384	+ 87	- 87	+273	-273	+ .0523
+162	-162	+198	-198	+ .9511	+139	-139	+221	-221	+ .7547	+116	-116	+244	-244	+ .4384	+ 93	- 93	+267	-267	+ .0523
+19	-19	+341	-341	+ .9455	+ 42	- 42	+318	-318	+ .7431	+ 65	- 65	+295	-295	+ .4226	+ 88	- 88	+272	-272	+ .0349
+161	-161	+199	-199	+ .9455	+138	-138	+222	-222	+ .7431	+115	-115	+245	-245	+ .4226	+ 92	- 92	+268	-268	+ .0349
+20	-20	+340	-340	+ .9397	+ 43	- 43	+317	-317	+ .7314	+ 66	- 66	+294	-294	+ .4067	+ 89	- 89	+271	-271	+ .0175
+160	-160	+200	-200	+ .9397	+137	-137	+223	-223	+ .7314	+114	-114	+246	-246	+ .4067	+ 91	- 91	+269	-269	+ .0175
+21	-21	+339	-339	+ .9336	+ 44	- 44	+316	-316	+ .7193	+ 67	- 67	+293	-293	+ .3907	+ 90	- 90	+270	-270	+ .0000
+159	-159	+201	-201	+ .9336	+136	-136	+224	-224	+ .7193	+113	-113	+247	-247	+ .3907					
+22	-22	+338	-338	+ .9272	+ 45	- 45	+315	-315	+ .7071	+ 68	- 68	+292	-292	+ .3746					
+158	-158	+202	-202	+ .9272	+135	-135	+225	-225	+ .7071	+112	-112	+248	-248	+ .3746					

Step 3

Perform mathematical calculations using the following procedures:

- ☐ Substitute known values into the moon altitude equation.
- ☐ Perform required calculations within the parenthesis.
- ☐ Determine Sin/Cos values for the number within each parenthesis. (Refer to tables D-2 and D-3 for the sine/consine values.)
- ☐ Perform required calculations between parenthesis.
- ☐ Determine the Arcsin by locating the angle with the closest sine function to the resulting value of the moon altitude equation. The Arcsin value is always located between 0° and 90°.
- ☐ Determine the position of the moon; e.g., above or below the horizon, and if it is increasing or decreasing in altitude. Anytime the resulting Arcsin value is a minus (-) the moon is below the horizon. If the moon GHA is less than your longitude, the moon altitude is increasing. If the GHA is greater than your longitude, the moon altitude is decreasing. In the example, the moon is increasing in altitude.

NOTE: It is not essential to compute the moon altitude for every hour of the night. By noting the time relation between sunset (EECT) and sunrise (BMCT) and moonrise and moonset you can accurately estimate the hours when a low and high light level will exist. Remember moonrise and/or moonset will not always occur on the day you are computing data for the light level calendar. When this occurs, refer to the preceding day to determine moonrise/moonset.

PERCENT ILLUMINATION

A second unknown that must be determined before the light level can be predicted is the percent of moon illumination. This value can be obtained from table D-4, "Percentage of Moon Illumination." This table is prepared by the United States Air Force Weather and is available at all Air Force Weather Detachments.

The days of the month are shown on the left and the months of the year are depicted across the top. To determine the percentage of illumination of the moon for a particular day, identify the day and month of concern and read the value where the two columns cross. As an example, on 5 December 1978, the percentage of illumination is .28 percent. Remember, this chart

TABLE D-4. PERCENTAGE OF MOON ILLUMINATION.

Taken From: The American Ephemeris and Nautical Almanac for the Year 1978 US Govt Printing Office, 1978.

1978 UNIVERSAL TIME												
DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	.65	.50	.65	.46	.37	.21	.17	.08	.03	.02	.00	.01
2	.55	.39	.54	.35	.27	.14	.10	.04	.00	.00	.02	.04
3	.45	.28	.43	.24	.18	.07	.05	.01	.00	.01	.06	.10
4	.34	.18	.32	.15	.11	.03	.02	.00	.02	.03	.13	.18
5	.24	.10	.21	.08	.05	.01	.00	.01	.05	.08	.21	.28
6	.15	.04	.13	.03	.02	.00	.00	.04	.11	.15	.31	.39
7	.07	.01	.06	.00	.00	.02	.02	.08	.18	.24	.42	.50
8	.02	.00	.02	.00	.01	.05	.06	.14	.27	.34	.54	.61
9	.00	.03	.00	.02	.03	.09	.11	.22	.37	.45	.65	.71
10	.01	.07	.01	.06	.08	.15	.18	.31	.48	.57	.75	.80
11	.05	.14	.04	.12	.13	.23	.26	.41	.60	.68	.84	.88
12	.11	.22	.10	.18	.20	.31	.35	.52	.71	.78	.91	.94
13	.19	.31	.17	.26	.29	.41	.45	.63	.81	.87	.96	.98
14	.29	.41	.25	.35	.37	.51	.56	.74	.89	.94	.99	1.00
15	.39	.51	.33	.45	.47	.61	.66	.83	.96	.98	1.00	1.00
16	.49	.60	.43	.54	.57	.71	.77	.91	.99	1.00	.98	.98
17	.59	.69	.52	.63	.66	.80	.86	.97	1.00	.99	.95	.94
18	.68	.78	.62	.73	.76	.88	.93	1.00	.98	.96	.90	.89
19	.76	.85	.71	.81	.84	.95	.98	.99	.94	.91	.84	.83
20	.84	.91	.79	.88	.91	.99	1.00	.96	.88	.85	.76	.75
21	.90	.96	.86	.94	.97	1.00	.99	.91	.80	.77	.67	.66
22	.95	.99	.92	.98	.99	.98	.95	.83	.71	.69	.58	.57
23	.98	1.00	.97	1.00	1.00	.93	.88	.75	.62	.60	.49	.47
24	1.00	.99	.99	.99	.97	.86	.80	.65	.52	.50	.39	.38
25	.99	.96	1.00	.95	.91	.76	.70	.55	.43	.41	.30	.28
26	.97	.92	.98	.89	.83	.66	.60	.45	.33	.32	.21	.19
27	.93	.84	.94	.81	.74	.55	.49	.36	.25	.23	.13	.11
28	.87	.75	.87	.71	.63	.45	.39	.27	.17	.15	.07	.05
29	.80		.78	.60	.52	.34	.30	.19	.10	.09	.03	.01
30	.71		.68	.49	.41	.25	.22	.12	.05	.04	.00	.00
31	.61		.57		.30		.14	.07		.01		.02

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TABLE D-3. TRIGONOMETRIC FUNCTION TABLES (COSINE).

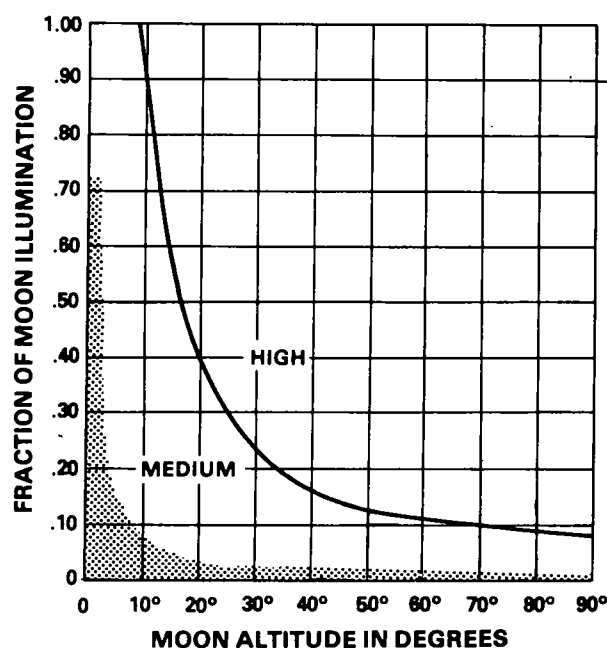
BRIGHTNESS CHART

only tells you what percentage of the moon will be visible for a particular 24-hour period.

Now that you know the moon altitude and the percentage of moon illumination, you can predict the light level using the

brightness chart (table D-5). The altitude of the moon (0-90°) is shown along the bottom of the chart and the fraction of moon illumination (0-100%) along the left edge. Within these boundaries are drawn two curves which divide the area into three levels of light (low, medium, and high).

TABLE D-5. BRIGHTNESS CHART.



To determine the light level, enter the brightness chart along the bottom at the altitude of the moon (20°). Move vertically to the horizontal line representing the fraction of moon illumination (.28%). The point of intercept will fall within one of the three levels of illumination. In the example used, a mid light level will exist on 5 December 1978 at 2100 hours. A table should be prepared identifying the time when the light level changes for the entire night and each day of the month (table D-6).

Although the light level can be predicted from the brightness chart, you must realize that varying intensities of light exist for

shadows, cloud coverage, and visibility restrictions of light intensity. When conducting terrain flight, much of the flight

TABLE D-6. PREDICTION NIGHT LEVELS (DECEMBER 1978).

DAY	LOW	MID	HIGH
1	1706-0557		
2	1706-0558		
3	1945-0559	1706-1945	
4	2110-0600	1706-2110	
5	2220-0600	2020-2220	1706-2020
6	2330-0601	2240-2320	1707-2210
7	0010-0602	2310-0010	1707-2310
8	0130-0603	0040-0130	1707-0040
9	0242-0603	0145-0242	1707-0145
10	0339-0604	0245-0339	1707-0245
11	0436-0605	0345-0436	1707-0345
12	0531-0605	0445-0531	1708-0445
13		0540-0606	1708-0540
14		1707-1800	1800-0607
15	1709-1803	1803-1845	1845-0607
16	1709-1854	1854-1945	1945-0608
17	1709-1945	1945-2030	2030-0609
18	1710-2037	2037-2130	2130-0609
19	1710-2129	2129-2230	2230-0610
20	1711-2221	2221-2320	2320-0610
21	1711-2330	2330-0020	0020-0611
22	1711-0030	0030-0120	0120-0611
23	1712-0120	0120-0230	0230-0612
24	1713-0220	0220-0345	0345-0612
25	1713-0318	0318-0420	0420-0612
26	1714-0437	0437-0613	
27	1714-0613		
28	1715-0614		
29	1716-0615		
30	0716-0615		
31	0716-0615		

each light level. Most critical is the division between mid and low light. Light intensity near this division may be insufficient to perform the mission even though a mid light level is indicated. Also, the brightness chart does not consider the effect of

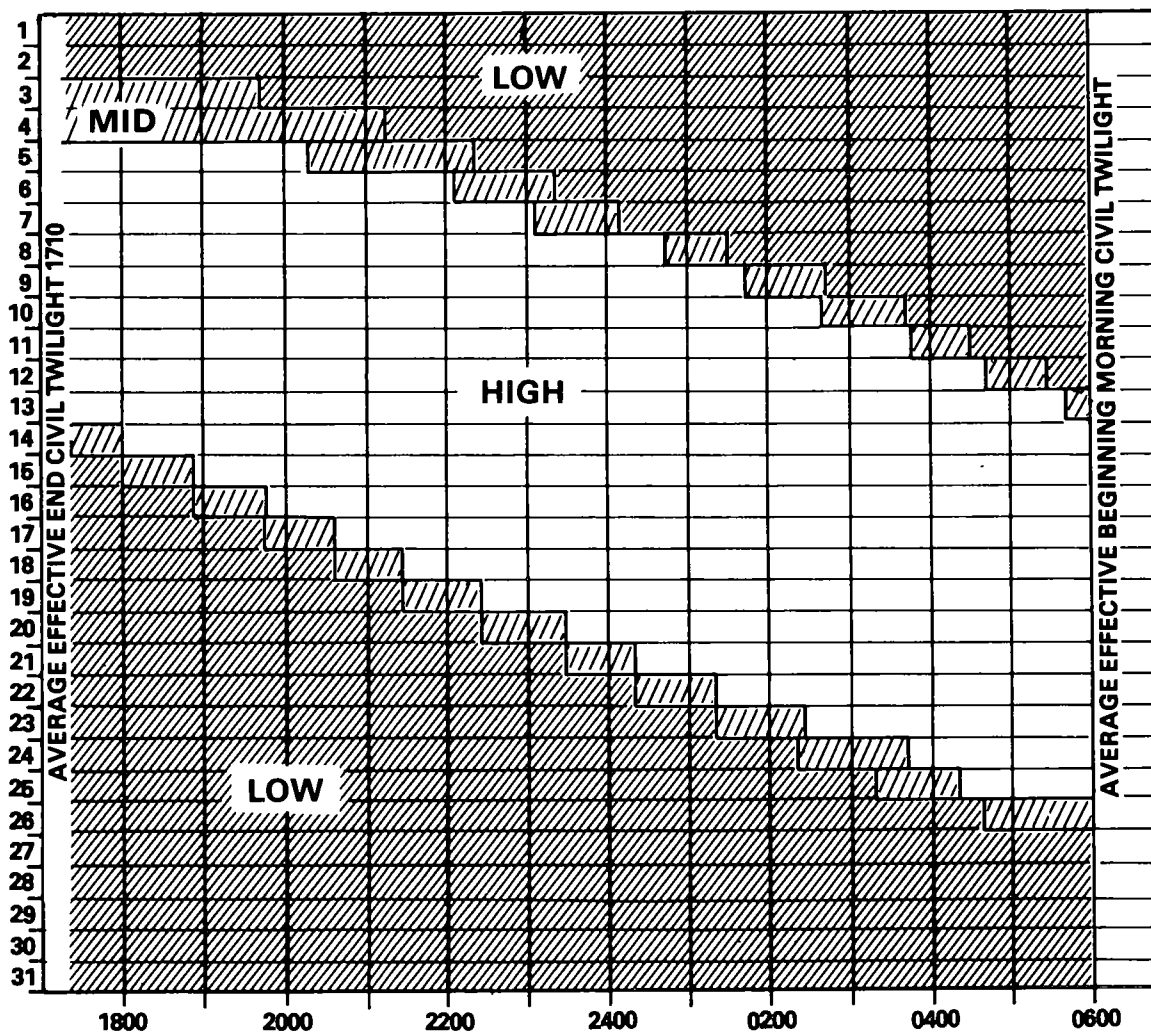
will be flown within the shadow of a terrain feature unless the moon is high enough on the horizon to eliminate shadows. As a rule, if the moon is 30° or more above the horizon, the effect of shadows is not a limiting factor for terrain flight.

LIGHT LEVEL CALENDAR

Because the light level will vary throughout the night, it is necessary to develop a procedure which will allow you to determine at a glance the best time period for conducting night aviation operations. By constructing a light level calendar, this information can be easily determined. Normally, a light level calendar is constructed for a month and several calendars are constructed in advance.

After determining the hours when each light level will occur for each night for an entire month, construct a light level calendar (table D-7). First draw a vertical and horizontal line. Along the horizontal line, construct a scale representing the hours of darkness. Along the vertical line, construct a scale representing the days of the month. Plot the light level for the hour and day on the calendar. After the plots are complete, join the areas of equal lighting to form divisions of light level.

TABLE D-7. LIGHT LEVEL CALENDAR (DECEMBER 1978).



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APPENDIX E**HOVER POWER CHECK****GENERAL**

Before conducting terrain flight, it is essential that you know if there is sufficient torque available to hover or land the aircraft out-of-ground-effect (OGE) in a downwind condition. To determine this information, you must refer to the performance charts in the Operator's Manual (-10) and compute the torque required for the specific condition of flight. Presented within this appendix are the procedures for developing a performance planning card. No attempt is made to teach the mechanics of how data is obtained from the charts. For specific information on how to interpret the performance data charts, refer to the Operator's Manual (-10) or TC 1-10.

PREFLIGHT PLANNING

Before conducting the inflight power checks, you must first develop a performance planning card. With the information contained on the card, you can conduct an inflight power check to determine if sufficient torque is available to perform the mission. For the purpose of this discussion, the performance chart for the UH-1 helicopter will be used. Although the charts for the different categories of helicopters will vary, the information obtained is similar.

You must first know the maximum torque the engine is capable of developing based on the pressure altitude, temperature, and the calibration factor of the engine. Remember the chart does not take into account any degradation of power due to wear or improper maintenance. An indication that you can use to determine the condition of the engine is the engine gas temperature. The more temperature deviates from the normal, the less efficient the engine. The engine health indicator test (HIT) check must be performed before performing the power check to confirm that the engine is operating within the established temperature range. If the temperature deviates more than 20°, a noticeable loss of torque will be experienced. Using the following information, it is determined from the maximum torque available chart that aircraft 67-2209 is capable of developing 44 pounds per square inch (psi) indicated torque.

Pressure altitude	5,000 ft
Free-air temperature	20°C
Calibration factor	59

NOTE: Calibrated torque values must be converted to indicated torque when applying the value to the aircraft torque gage.

The next step is to determine the maximum gross weight at which the helicopter will hover OGE, based on maximum available torque. Using the above information to enter the hover chart, the maximum OGE (50 ft) gross weight is determined to be 8,600 pounds.

NOTE: If the pressure altitude and temperature of the landing point is unknown, use the worst case to insure adequate torque is available to accomplish the mission.

Now that the capability of the aircraft is known, a procedure must be developed which will allow you to determine if the mission weight is within the operating limitations of the aircraft. This is accomplished by computing the torque required to hover the aircraft at 5 feet with the maximum OGE gross weight. From the hover chart, it is determined that the torque required is 37 psi.

NOTE: A common misconception is that the calibration factor changes when maintenance is performed on the engine; e.g., removal or replacement of components within the compressor or the N₂ turbine section. This is not true. The calibration factor is based on variations that exist within the engine housing. These differences cause minor variations in oil pressure which provide torque indications. Whenever the engine housing is changed or modified, the maintenance facility is required to determine the new calibration factor and to stamp it into the engine data plate. Also this informa-

tion will be entered on the engine green run sheet that will remain a permanent part of the engine historical records.

HOVER POWER CHECK

The information you have computed can now be used in the inflight power check. With the aircraft loaded in its mission configuration, fly it to a 5-foot hover and perform a 360-degree left pedal turn; or position the aircraft so that the wind is 60° to 90° to the right. If the torque required to perform this maneuver is equal to or less than the computed torque (37 psi), the gross weight of the helicopter does not exceed the maximum gross weight for hovering OGE. In this case, sufficient torque is available to conduct a terrain flight mission. If the torque required to hover is greater than the computed torque, the mission weight of the aircraft exceeds the gross weight limitation of the aircraft, and the load must be reduced. Conversely, if the torque is less than what is required, additional weight can be added. A rule of thumb to follow is to reduce or add 200 pounds for each 1 pound of torque above or below the go-no-go torque.

When conducting the power check in an area where the inflight conditions cannot be duplicated at a 5-foot hover; e.g., a confined area where the wind is blocked by trees, the aircraft should be flown to an altitude clear of obstacles to check for controllability. Normally, upon reaching an altitude clear of obstacles and aircraft control can be maintained, forward flight is initiated from this point. If conditions are such that controllability cannot be determined when aligned on the takeoff heading and threat weapons are not a factor, a left

360° turn may be performed to insure that control limitations of the aircraft are not exceeded. If at any time during the maneuver it appears the power available is insufficient or the antitorque capability of the aircraft becomes ineffective, reduce collective and land.

DETERMINING PAYLOAD

Before arriving at the pickup zone (PZ), it may be desirable to know the approximate number of troops or pounds of cargo that can be loaded aboard the aircraft. The information required to determine the payload can be computed during your premission planning and added to the performance planning card.

To compute the payload of the aircraft, you must know the operating weight of the aircraft plus fuel. Knowing this information, you can now compute the torque required to hover at 5 feet. For example, you determine the operating weight plus fuel to be 7,100 pounds. With this information, it is determined that 30 psi indicated torque is required to perform a 5-foot hover.

PERFORMANCE PLANNING CARD

Maximum torque - 44 psi
37 psi (go-no-go) - 8,600 lbs
30 psi (empty wt) - 7,100 lbs

Prior to departure, fly the aircraft to a 5-foot hover and determine the torque required to hover the aircraft. If, for example, the torque required to hover the aircraft is 32 psi, you can assume the aircraft weighs 400 pounds more than you

estimated. Based on these findings, you determine the payload to be 1,100 pounds.

8,600 pounds mission load
7,500 pounds operating weight plus fuel
1,100 pounds allowable payload

With this information, you can accurately estimate the number of troops or amount of cargo to be loaded on the aircraft at the PZ. A hover power check with the mission load should also be performed to confirm that the gross weight does not exceed the limitations of the aircraft.

In addition to providing information relating to weight limitations, this check also provides a confidence check of the torque gage. If, for example, the reading of the torque gage were greater than +4, there may be an error in the sensing unit as well as in weight estimation; therefore, action should be taken to check the accuracy of the gage.

CAUTION: Even though the aircraft may be within the weight limitations, the center of gravity (CG) limits may be exceeded. An awareness of load configuration for identical load is essential as well as an inflight CG check of the controls.

DETERMINING ENGINE PERFORMANCE

As previously stated, the performance charts do not consider degradation of engine performance due to wear or improper maintenance. To accurately compute the

gross weight limitations of the aircraft, this information is needed. Although not a normal check for aviators, an engine topping check for most helicopters is performed during maintenance test flights by the maintenance officers. Information obtained during the topping check; e.g.,

maximum torque available, pressure altitude and temperature should be made available to the aviator. Using this information, the gross weight can be accurately computed and greater confidence is achieved in knowing the actual inflight capability of the aircraft.

GLOSSARY

- acceleration**—The rate of change of velocity with respect to time.
- advancing blade**—The rotor blade experiencing an increased relative wind because of airspeed.
- airfoil**—A surfaced body designed to produce a force when subjected to an airflow.
- airfoil section**—A cross section of an airfoil.
- airspeed**—The speed of an aircraft in relation to the air. It is a component of relative wind.
- altitude**—The elevation of an aircraft above a given reference plane.
- angle of attack**—The acute angle between the chord line of an airfoil and the resultant relative wind.
- angle of incidence** (Also called pitch angle.)—The angle of the rotor blade chord line with the plane of rotation (tip-path plane) of the rotor system.
- antitorque**—A method used to counteract the torque reaction which results from turning the rotor system.
- articulated rotor system**—A rotor system in which the hub is mounted rigidly to the mast, and the individual blades are mounted on hinge pins, allowing them to flap up and down and move forward and backward. Individual blades are allowed to feather by rotating about the blade grip retainer bearing.
- autorotation**—The action of turning a rotor system by airflow and not by engine power. The airflow may be produced by forward movement or descending through the air.
- axis**—The theoretical line extending through the center of gravity of an aircraft in each major plane.
- axis of rotation**—The center of rotation perpendicular to the plane of rotation.
- bank**—To roll about the longitudinal axis of the aircraft.
- blow back**—The tendency for the rotor disk to tilt aft as a result of flapping that is caused by the combined effects of dissymmetry of lift and transverse flow.
- camber**—The curvature of an airfoil.
- center of gravity**—The point within an aircraft through which, for balance purposes, the total force of gravity is considered to act.
- center of pressure**—A point along the chord line of an airfoil through which all the aerodynamic forces are considered to act.
- centrifugal force**—A force that tends to make rotating bodies move away from the center of rotation.
- centripetal force**—A force that counteracts centrifugal force by keeping a system a certain radius from the axis of rotation.
- chord**—The longitudinal dimension of an airfoil section, measured from the leading to trailing edge.

chord line—A straight line connecting the leading and trailing edges of an airfoil.

coefficient of drag (C_D)—A dimensionless number indicating the drag inefficiency of an airfoil which is determined by angle of attack and airfoil design. It is derived from wind tunnel testing.

coefficient of lift (C_L)—A dimensionless number indicating the efficiency of the airfoil which is determined by angle of attack and airfoil design. It is derived from wind tunnel testing.

collective feathering—The simultaneous change of pitch of all rotor blades in a rotor system an equal amount.

compressibility effects—A phenomenon resulting from the advancing blade approaching Mach I or the speed of sound, due to excessive forward speed. As the blade reaches the critical Mach number, a shock wave is formed. This shock wave changes the density of the air and causes separation of the airflow rearward of the shock wave. The most adverse effect is a shift of center of pressure from the first third of the chord position causing a severe twisting moment on the blade.

coning angle—The angle between the plane of rotation and the rotor blade.

cyclic feathering—The change of pitch of individual rotor blades independently of the other blades in the system.

dissymmetry of lift—The difference in lift exists between the advancing half of the rotor disk and the retreating half.

drag (D)—A force opposing the motion of a body through the air.

flapping—Up and down movement of a rotor blade.

friction—A force which opposes motion.

gravity—An attraction of two objects for each other that is dependent upon their mass and the distance between them.

ground effect—A condition of improved aircraft performance when operating near a surface.

gyroscopic precession—A phenomenon in rotating systems that makes all forces react with a movement 90° from the point of force in the direction of rotation.

induced drag (D_i)—Airfoil drag induced by the production of aerodynamic force.

kinetic energy—The energy of a system because of motion.

lead and lag—Movement of the rotor blade forward (lead) and aft (lag) of the radial line from the center of the main rotor shaft through the axis of the drag hinge.

lift (L)—The net force developed perpendicular to the relative wind.

mass—The amount of material in a body normally expressed in slugs.

mean camber line—A line drawn halfway between the upper and lower surfaces of an airfoil. On symmetrical airfoils, the mean camber line and the chord line are the same.

parasite drag (D_p)—Drag incurred from the nonlifting portions of the aircraft includes all form and skin friction drag.

pitch (attitude)—Movement about the lateral axis.

potential energy—The energy of a system derived from position.

power—The rate of doing work, often expressed in units of horsepower.

profile drag (D_o)—The parasite drag of the helicopter rotor blades.

relative wind (V)—The airflow relative to an airfoil.

airspeed velocity (V_a)—The component of the relative wind produced by forward movement of the aircraft.

flapping velocity (V_f)—The component of the relative wind produced by blade flapping.

- induced velocity (V_i)**—The induced vertical component of the relative wind, sometimes referred to as “downwash.”
- rotational velocity (V_r)**—The component of the relative wind produced by rotation of the rotor blades.
- retreating blade**—The rotor blade experiencing a decreased relative wind because of airspeed.
- retreating blade stall**—A stall that begins at or near the tip of the blade due to high angles of attack required to compensate for dissymmetry of lift.
- rigid rotor system**—A rotor system in which the rotor blades are fixed rigidly to the hub and not allowed to flap or lead and lag. The only action allowed is pitch change.
- roll**—Movement about the longitudinal axis.
- semirigid rotor system**—A rotor system in which the blades are connected to the mast by a trunnion that allows blades to flap. Pitch change (feathering) is allowed at the hub about the blade grip retainer bearing.
- settling with power**—A condition of powered flight where the helicopter settles in its own downwash.
- skid**—Rate of turn is greater than normal for the degree of bank established.
- slip**—Rate of turn is less than normal for the degree of bank established.
- slug**—The unit of mass that is accelerated at the rate of 1 foot per second when acted upon by a force of 1 pound weight.
- speed**—The rate at which an object moves.
- stall**—A condition of an airfoil at which it is at an angle of attack greater than the angle of attack of maximum lift.
- tail rotor**—The antitorque device of a single-rotor helicopter. Control of this rotor is through the foot pedals.
- tandem rotor system**—A main lifting rotor is used at each end of the helicopter. The rotor systems rotate in opposite direction to counteract torque.
- thrust**—The force which opposes drag. In rotary-wing aircraft, often expressed as the total lift of the rotor system (T_r).
- tip-path plane**—A plane defined by the circle scribed by the average flightpath of the blade tips in a rotor system. It is sometimes called the rotor disk.
- torque effect**—The reaction to the turning of the rotor system. If the rotor system turns counterclockwise, the fuselage reacts by turning clockwise. (See Newton's third law.)
- total aerodynamic force**—The total force developed by an airfoil (lift + drag).
- translational flight**—Any horizontal movement of the helicopter with respect to the air.
- translational lift**—Additional lift obtained because of airspeed.
- translating tendency**—The tendency of the single-rotor helicopter to move laterally during hovering flight (also called tail rotor drift).
- transverse flow effect**—A condition of increased drag in the aft portion of the rotor disk caused by the air having a greater downwash angle in the aft portion of the disk.
- vector**—A quantity having both magnitude and direction. Also a graphic illustration of such a quantity.
- velocity**—A vector quantity having both speed and direction.
- weight**—A measure of the mass of an object under the acceleration of gravity.
- work**—A force exerted over a given distance.
- yaw**—Movement about the vertical axis.



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16 APRIL 1979

By Order of the Secretary of the Army:

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General, United States Army
Chief of Staff

Official:

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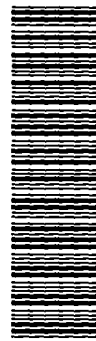
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